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Recent changes in Earth's surface temperature

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JPL Climate Science Center, 2017-05-05

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[5]University of California, Berkeley, U.S.A. [6]Independent researcher, Montréal, Canada [7]George Mason University, U.S.A [8]Tempo Analytics, Tempo, U.S.A

- NOAA build sea-surface temperature (SST) records from 1880—today

- Their techniques have been attacked by political groups because of changes post~1990s in temperature records

- We found that independent satellite data + other sources support NOAA's latest SST record and contradict the claims of political groups: Hausfather et al. (2017), *Science Advances*, doi: 10.1126/sciadv.1601207

Independent satellite + other data support the NOAA results

There is no evidence to support any claims like this

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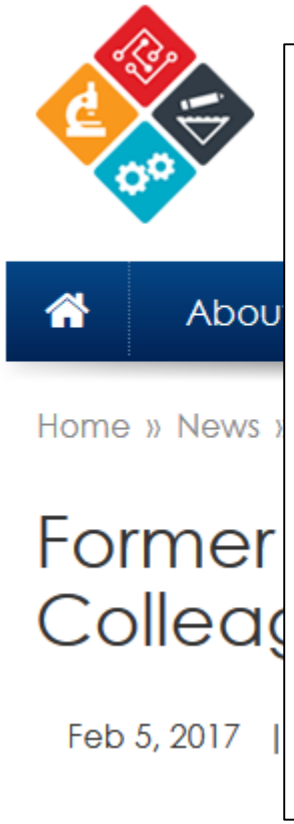


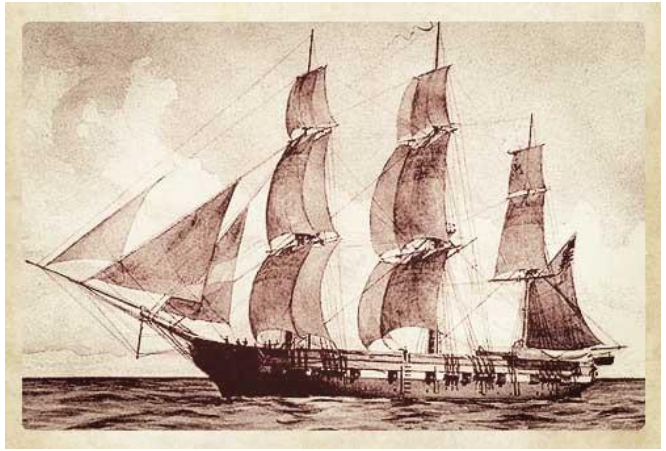
Two days later:
E&E News (February 7, 2017 at http://www.eenews.net/climatewire/stories/1060049630/)

"'Whistleblower' says protocol was breached but no data fraud

He specified that he did not believe that they manipulated the data upon which the research relied in any way"

History of SST measurements 1

- In 2015 NOAA updated ERSSTv3b to ERSSTv4 with new corrections for changing measurement type:



USS Dale, similar to USS Yorktown whose logbooks are in ICOADS (prior to ERSSTv4, illustration only, pic from http://www.visitingyorktown.com/ships.html)

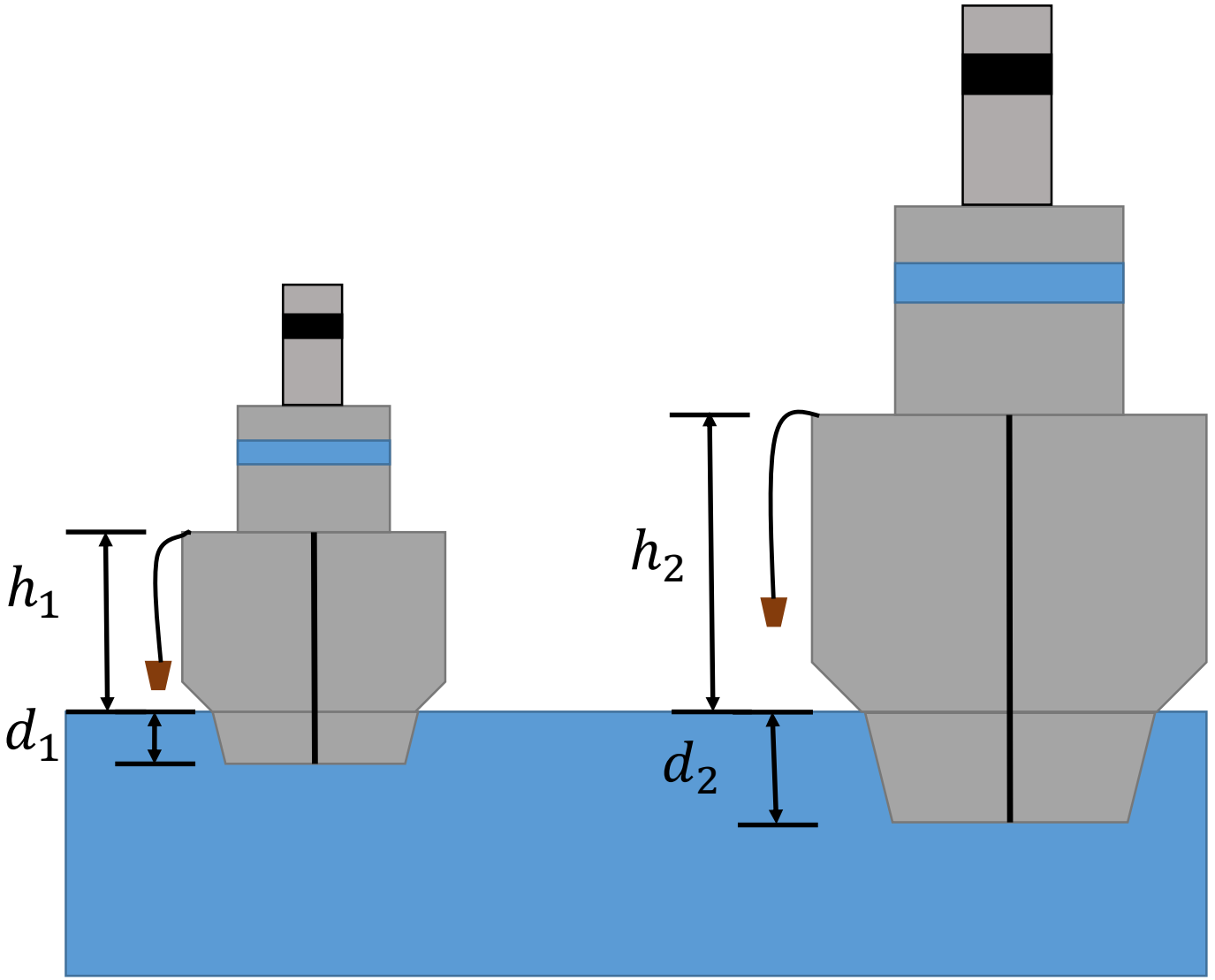
https://www.dwd.de/EN/ourservices/light_vessels/lightvessels.html

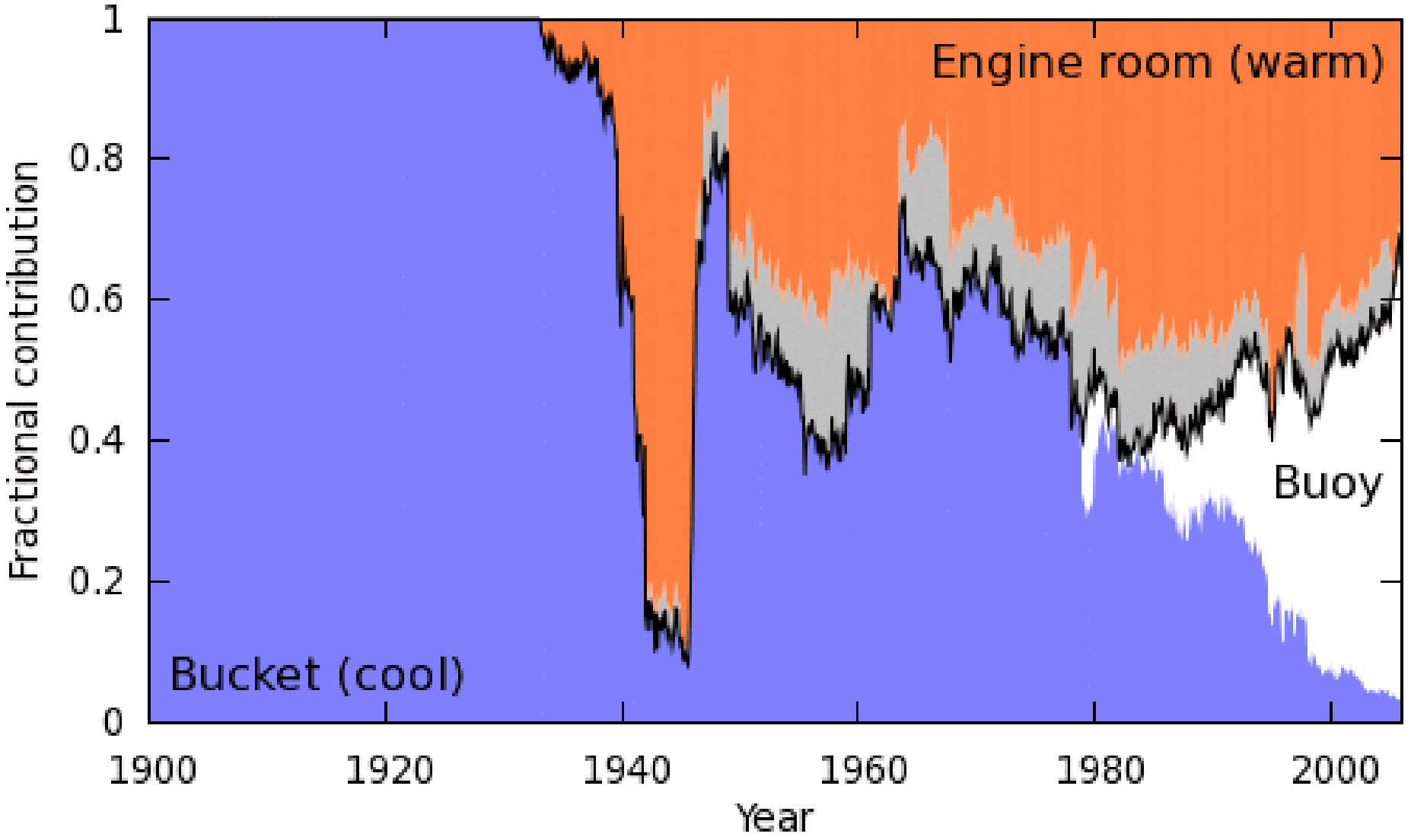
https://www.ncdc.noaa.gov/sites/default/files/styles/341px_width/public/ship1258-Linda-Stratton,-OAR-PMEL.jpg

History of SST measurements 2

- Higher ships allow more evaporation if they use buckets

- Deeper-draft ships measure deeper water if they use engine-room intake





Replotted Kennedy et al. (2011) *JGR* doi:10.1029/2010JD015220 at https://www.skepticalscience.com/hadsst3_a_detailed_look.html

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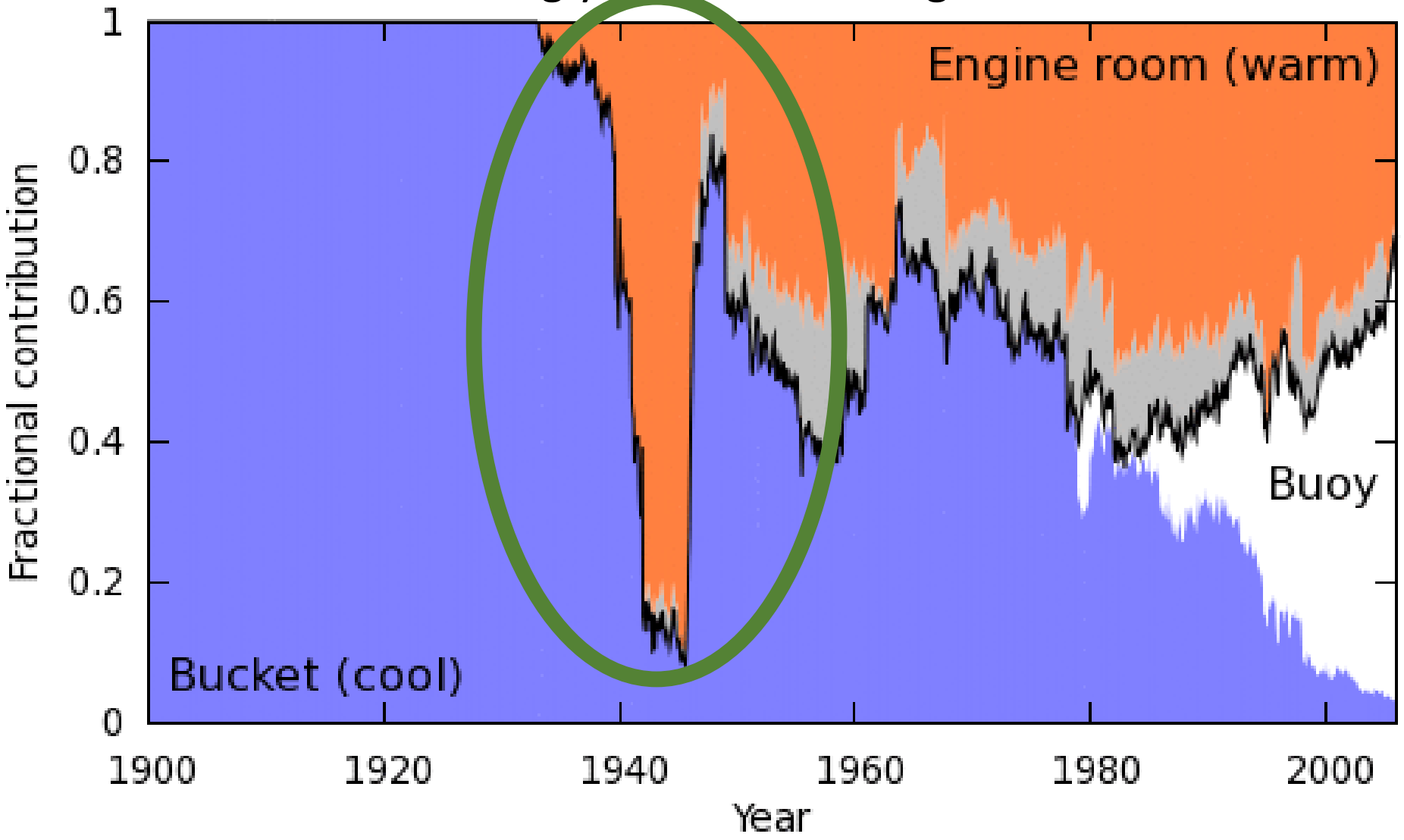
U.S. and Royal Navy used Engine-room intakes, but British merchant ships used buckets. War strongly affected coverage from British merchant ships.



Kennedy et al. (2011) *JGR* doi:10.1029/2010JD015220

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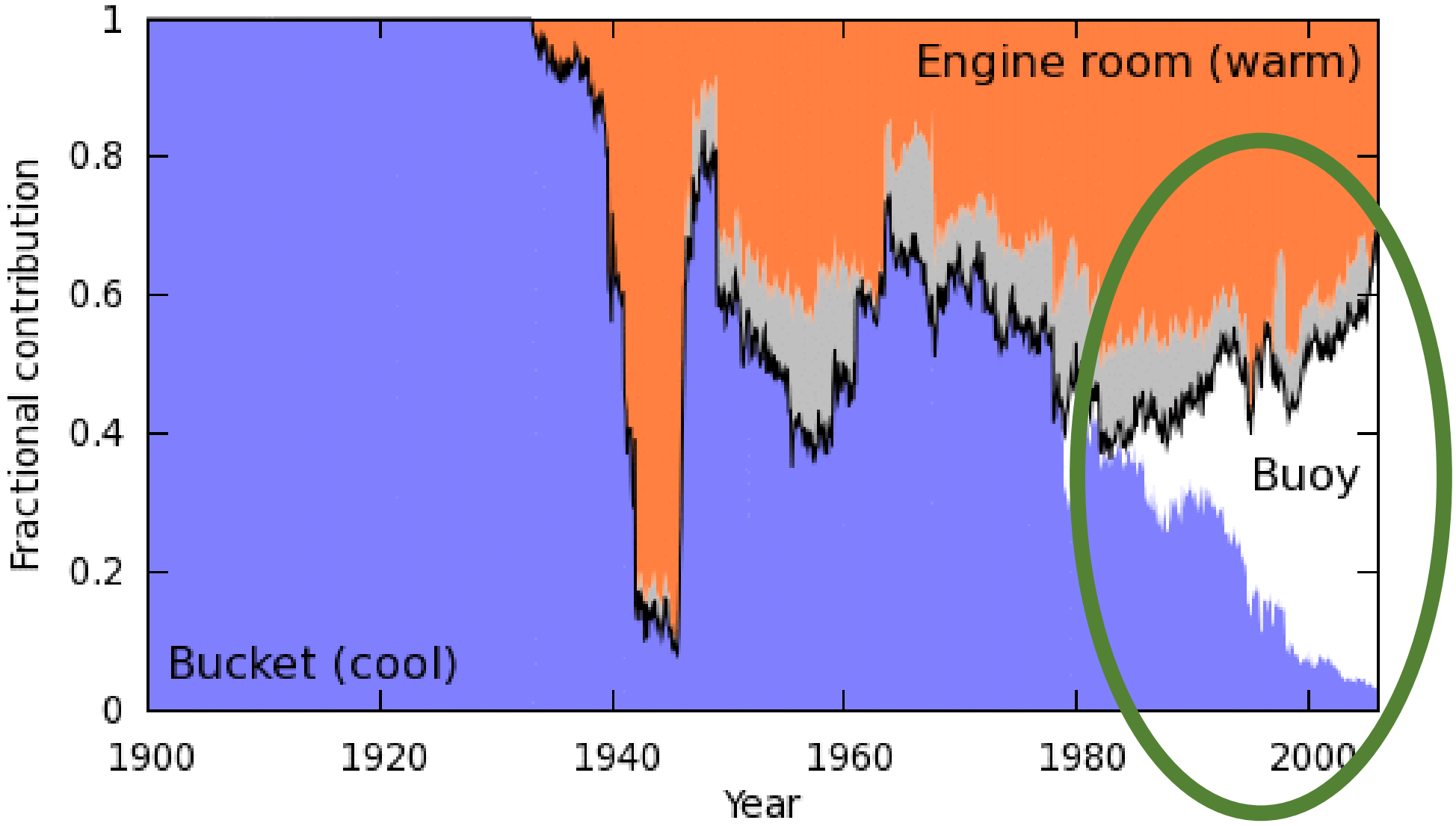
Recent years have seen more buoys deployed



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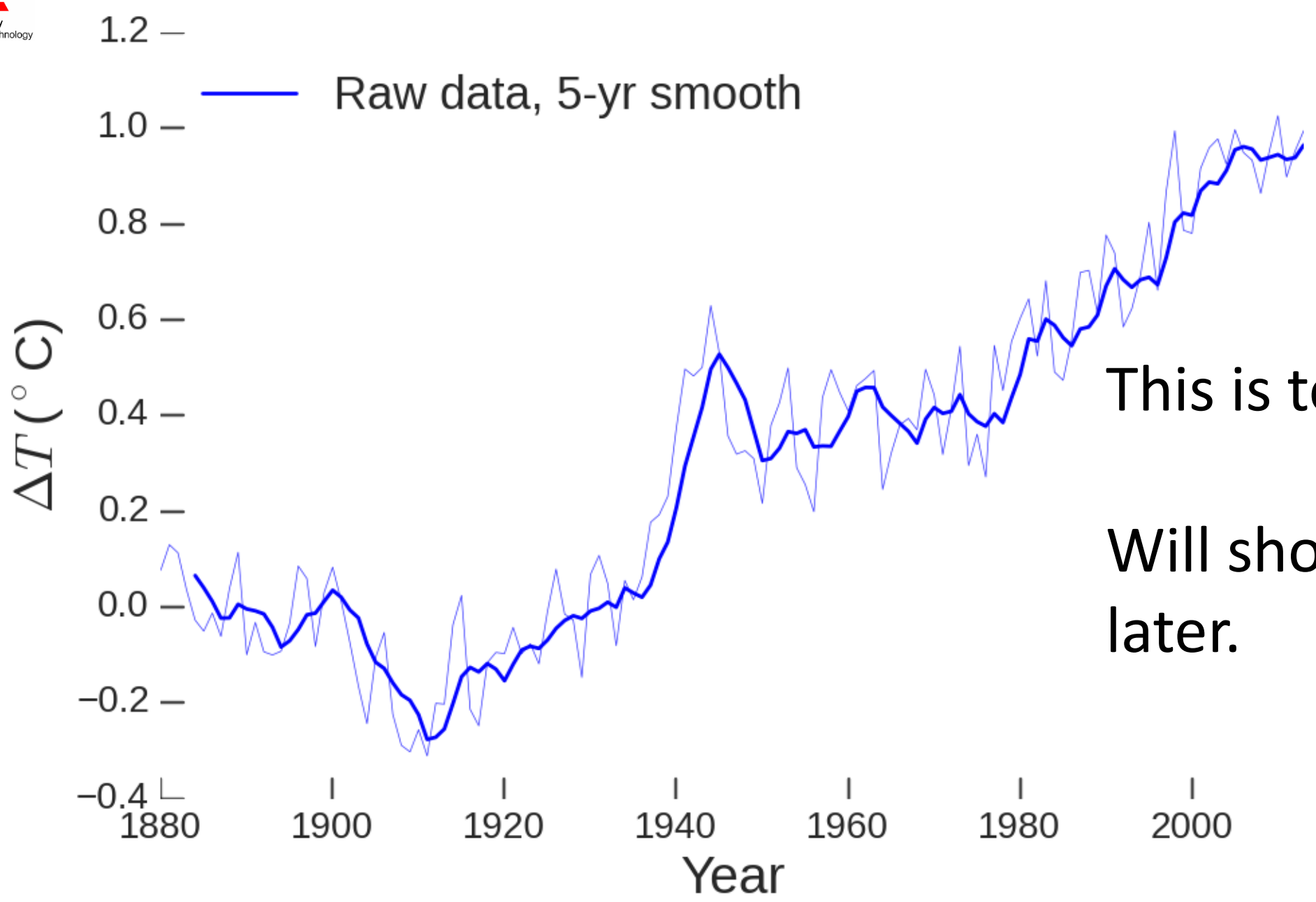

This is to 2013.

Will show rest later.

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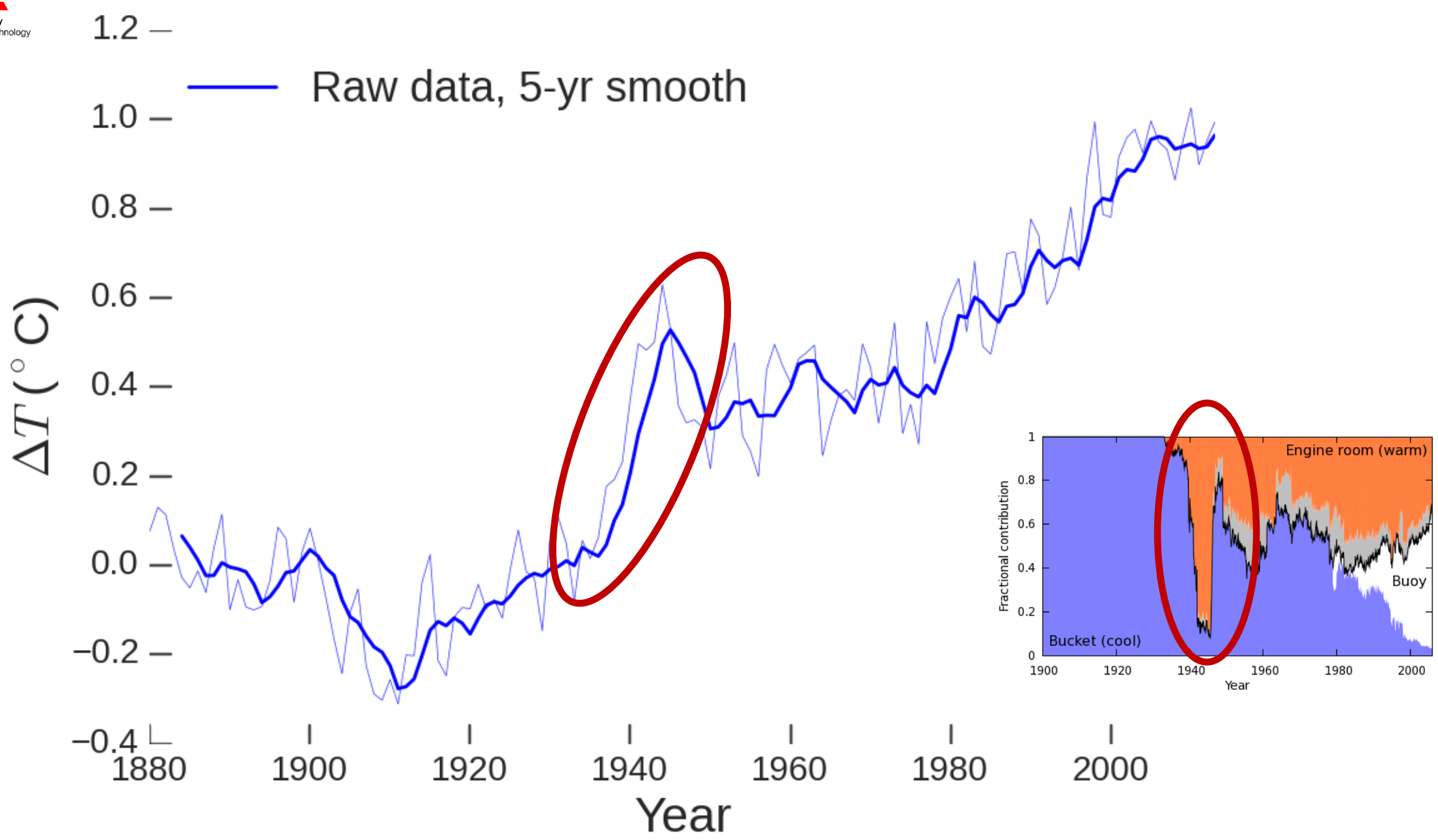

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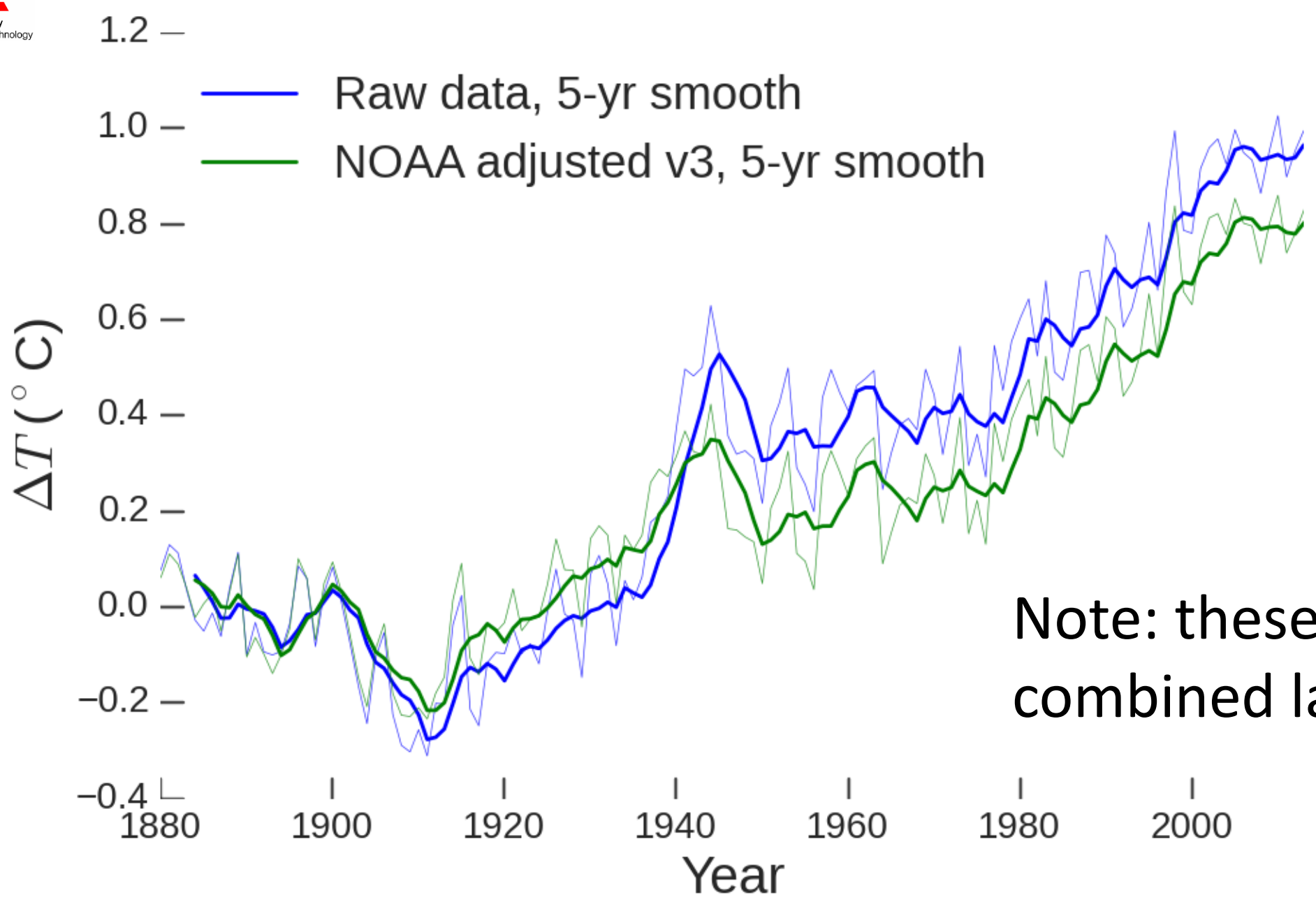

Note: these are combined land/ocean

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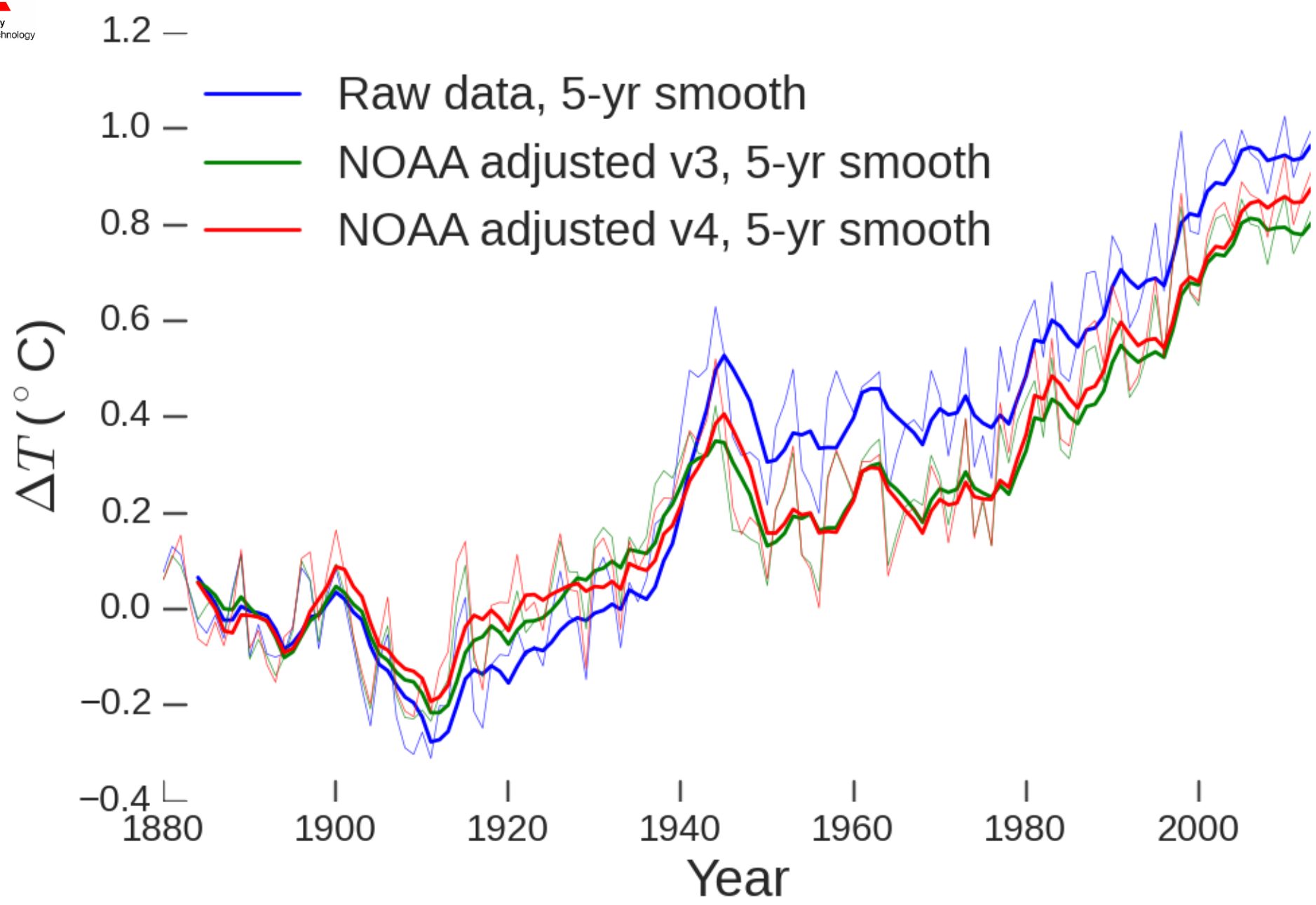

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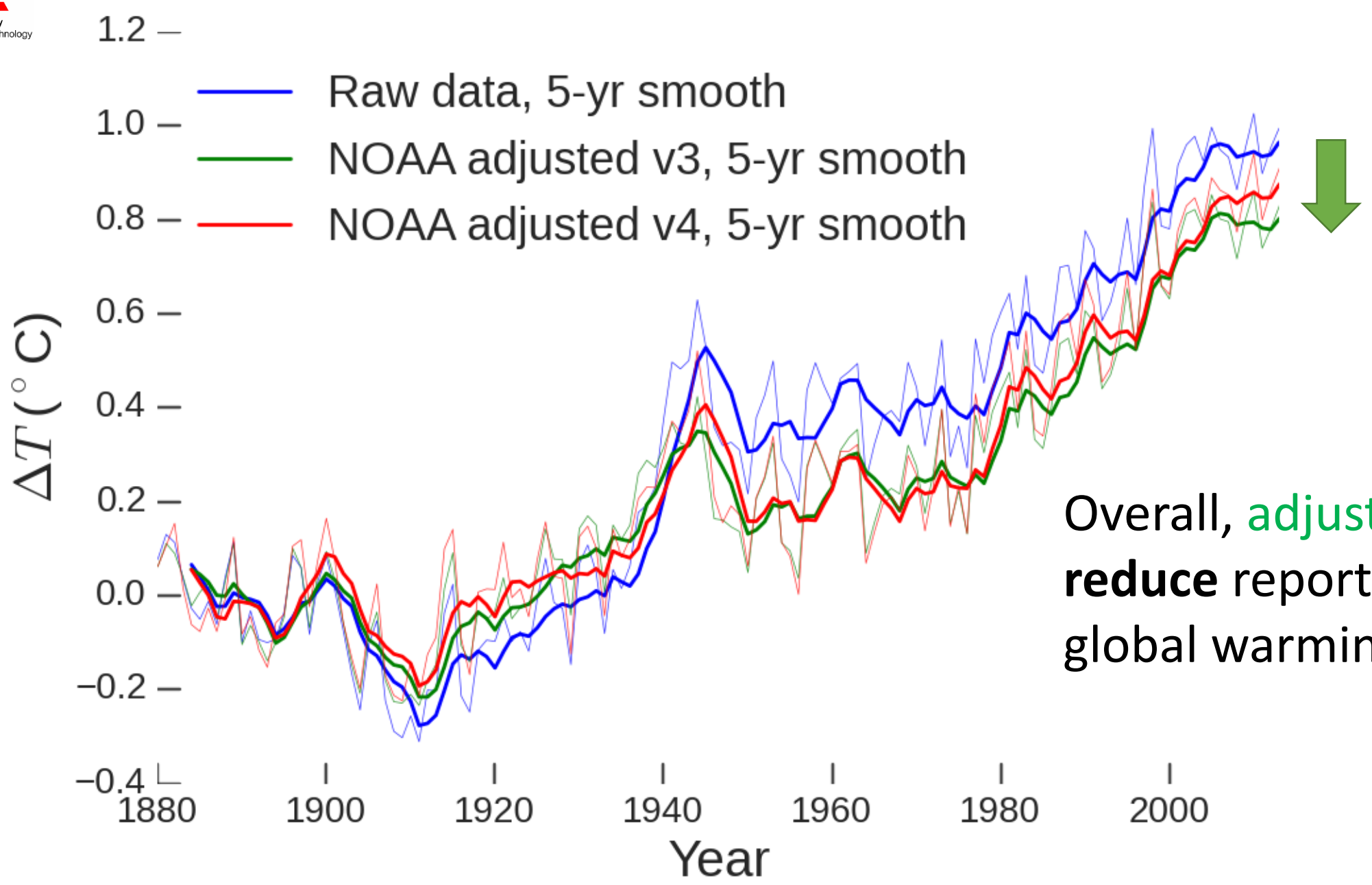

Overall, adjustments **reduce** reported global warming

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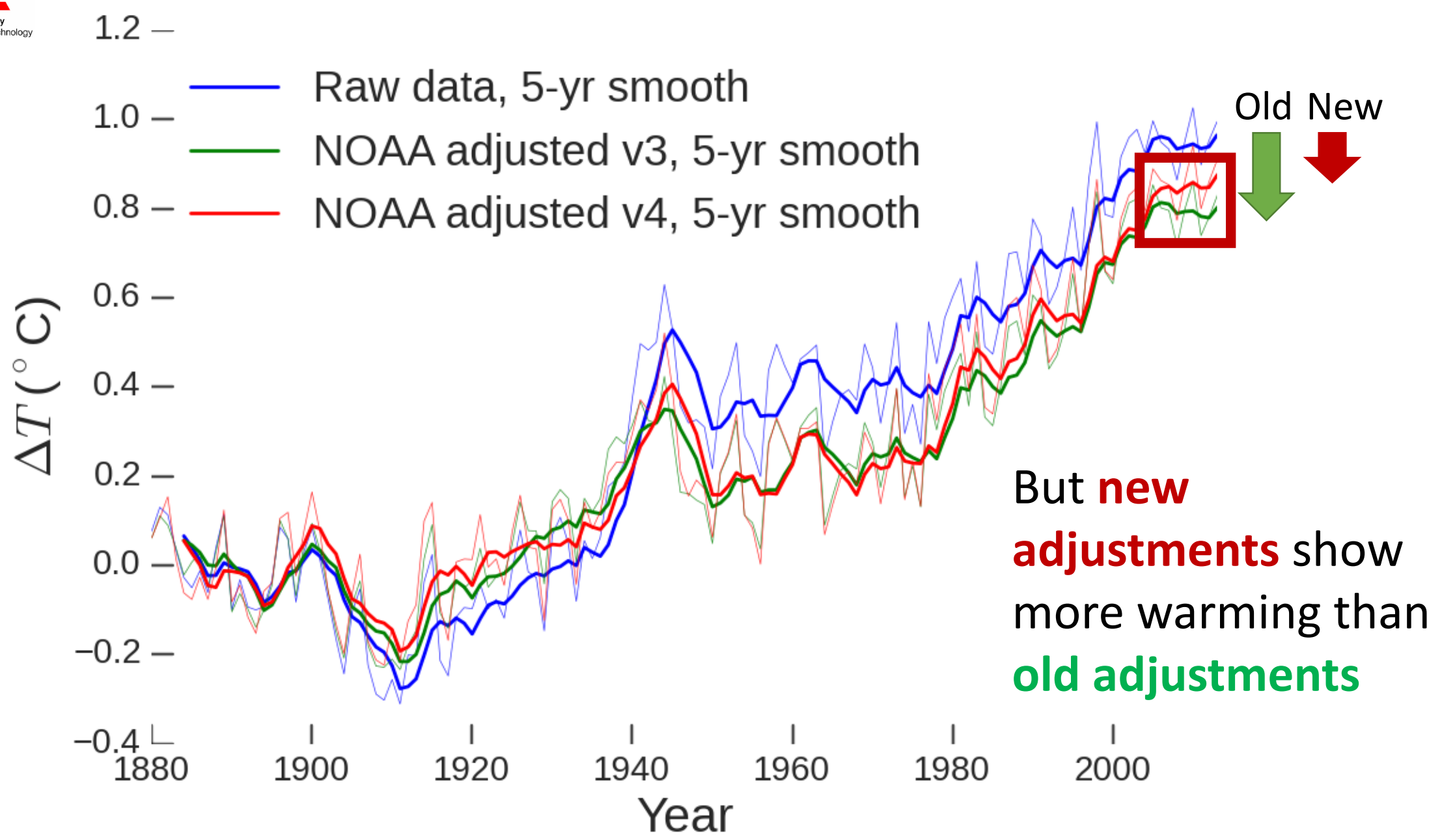

But **new adjustments** show more warming than **old adjustments**

Instrumentally homogeneous approach

1) NOAA combine different instruments to allow comparisons back to 1880

2) We’re interested in recent ~20 years where buoys come to dominate

3) Consider “instrumentally homogeneous” time series – buoys only, satellites only, Argo only (from 2005)

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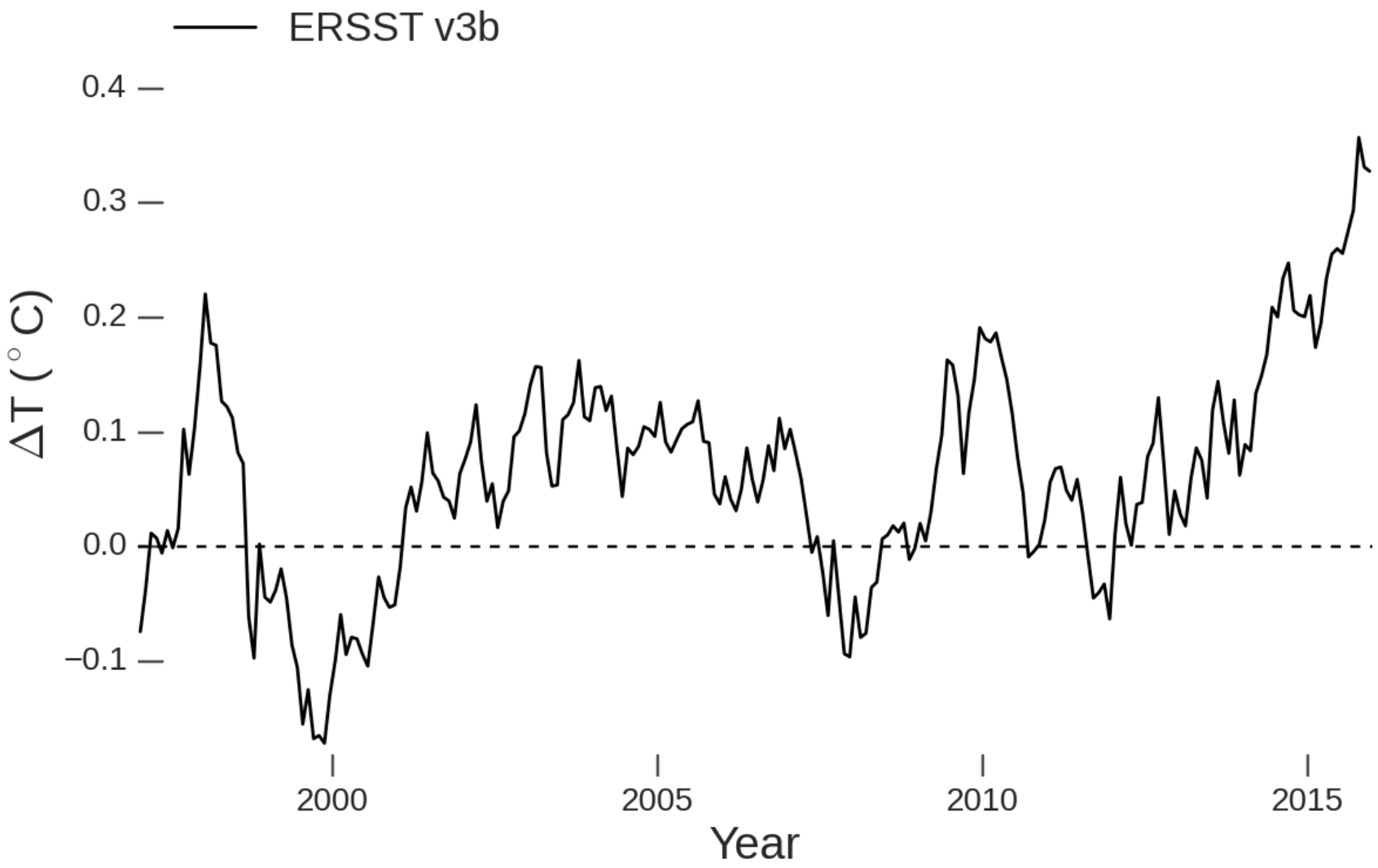
Old NOAA



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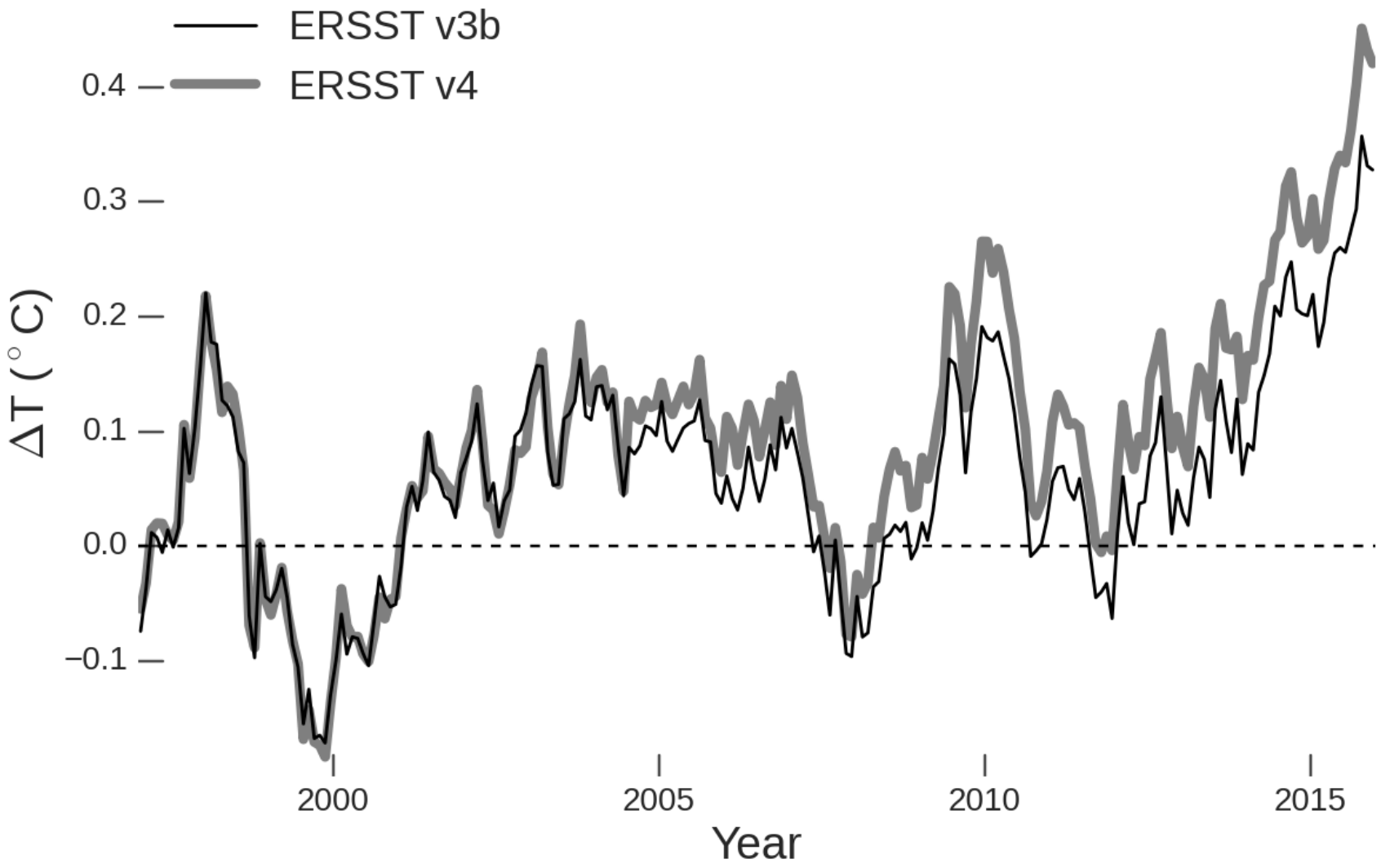
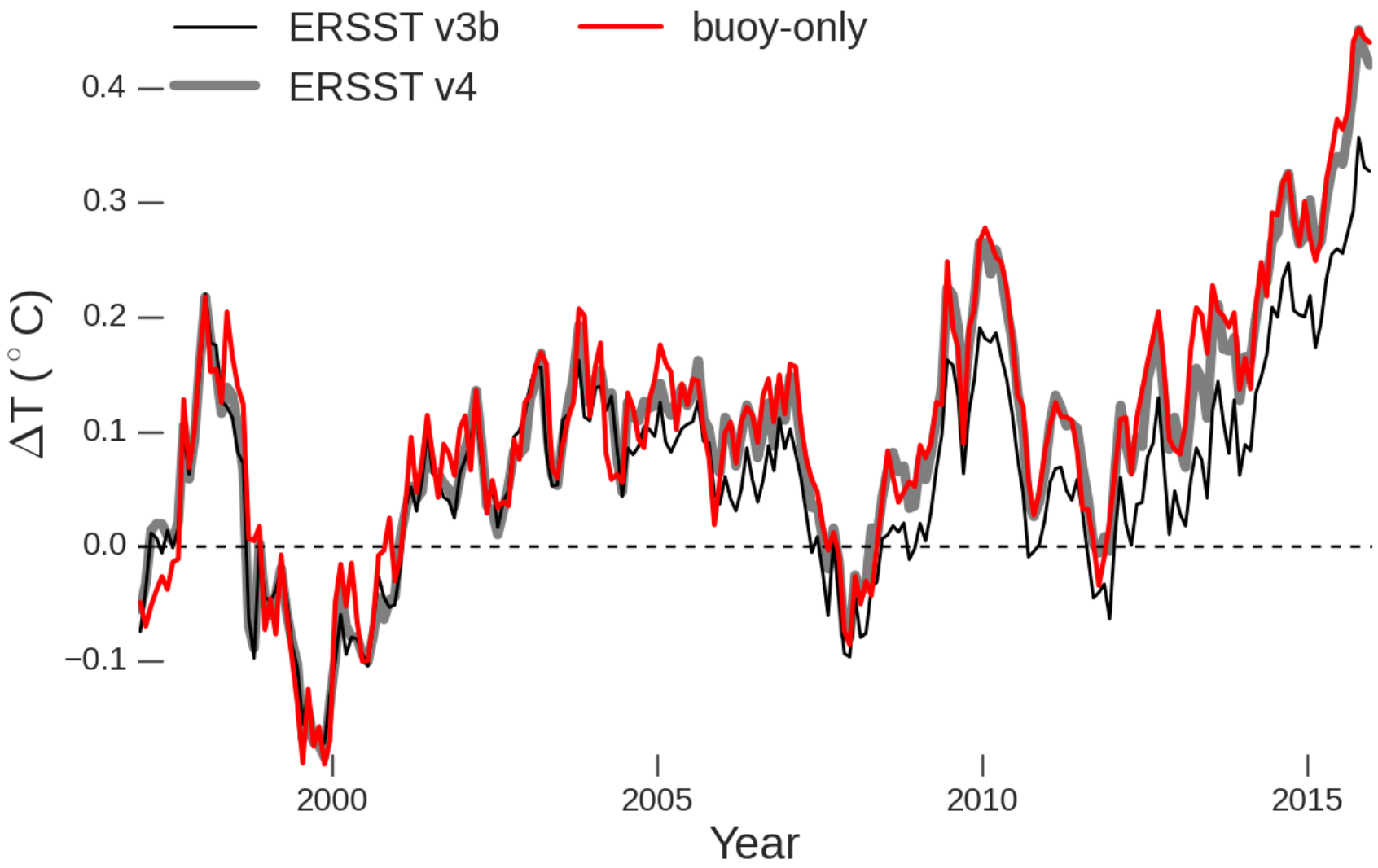
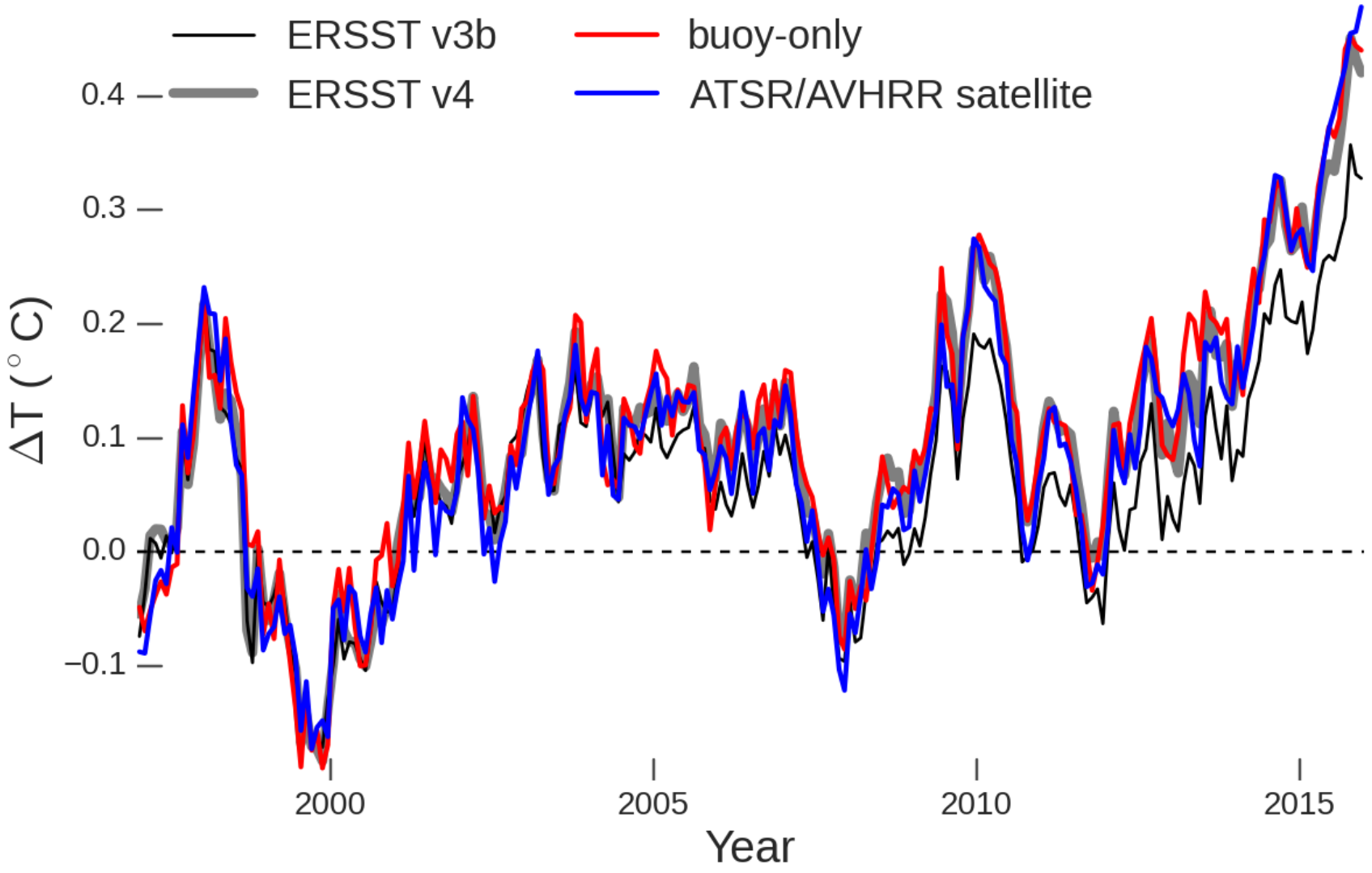
Old NOAA



Old NOAA


ERSST v3b
buoy-only
ERSST v4
0.4
0.3
0.2
0.1
0.0
−0.1
ΔT (°C)
2000
2005
2010
2015
Year

Old NOAA


ERSST v3b
ERSST v4
buoy-only
ATSR/AVHRR satellite
0.4
0.3
0.2
0.1
0.0
−0.1
ΔT (°C)
2000
2005
2010
2015
Year

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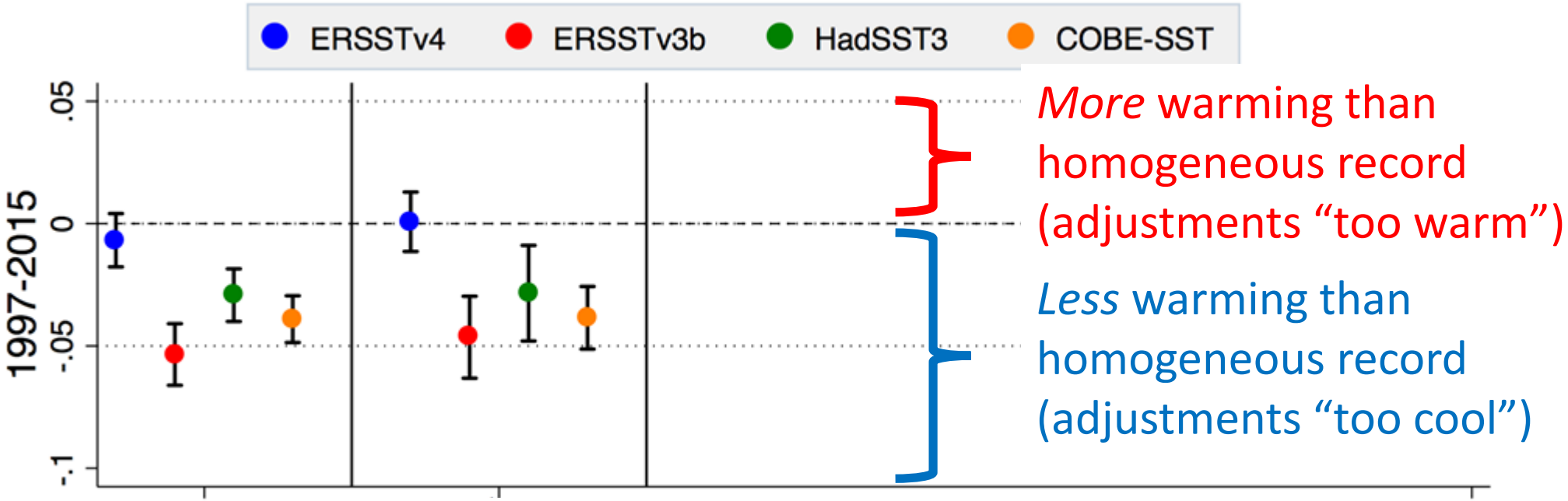
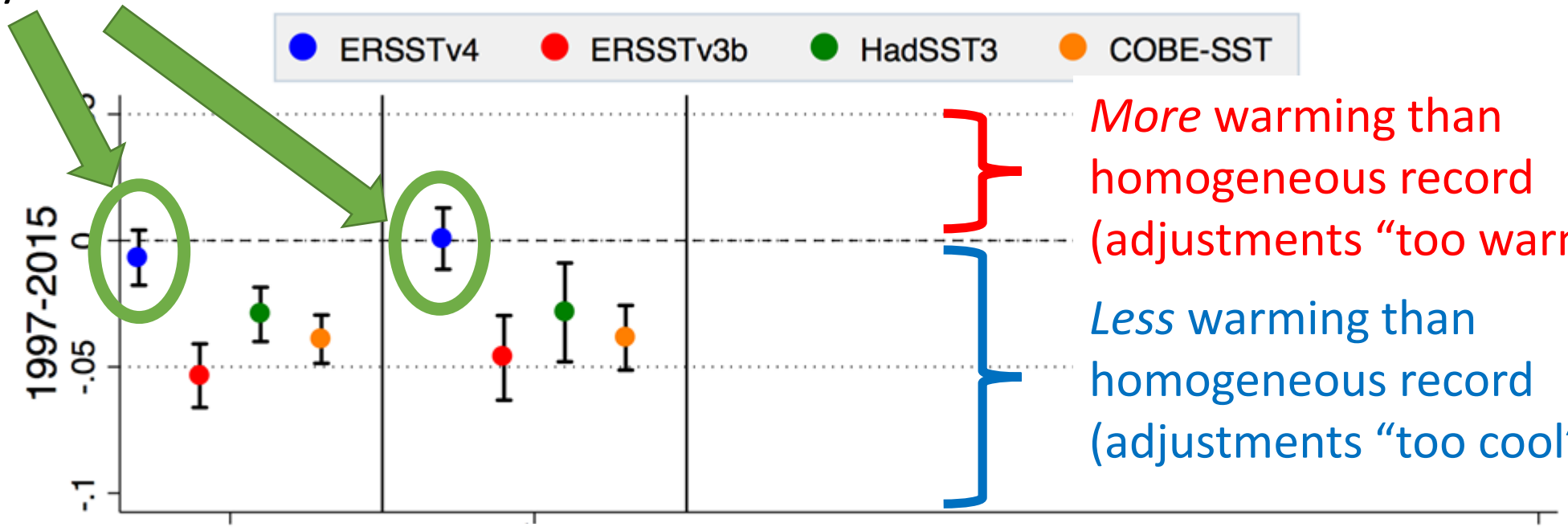
Trends in differences 1997—2015



Trends in differences 1997—2015

New NOAA trends agree with buoys and satellites



More warming than homogeneous record (adjustments "too warm")

Less warming than homogeneous record (adjustments "too cool")

Buoys

ESA CCI Satellite

Similar story over 2005—2015 with Argo

See: Hausfather et al. (2017) *Science Advances* doi: 10.1126/sciadv.1601207

SST summary

1) All data to check NOAA results are free online

2) Buoys are used in NOAA ERSST so are a form of verification – newer v4 trend verifies, but v3b does not, it's "too cool".

3) Independent satellite data validates newer v4, but v3b again "too cool". Independent Argo data supports this.

4) NOAA's v4 adjustments do well with changing instrument types.

CHANGE OF TOPIC

Enough about SSTs, let’s look at the both land and ocean

Recent warming

Global warming has been continuous since ~1970, there was no “pause/hiatus” in global warming. Fact.

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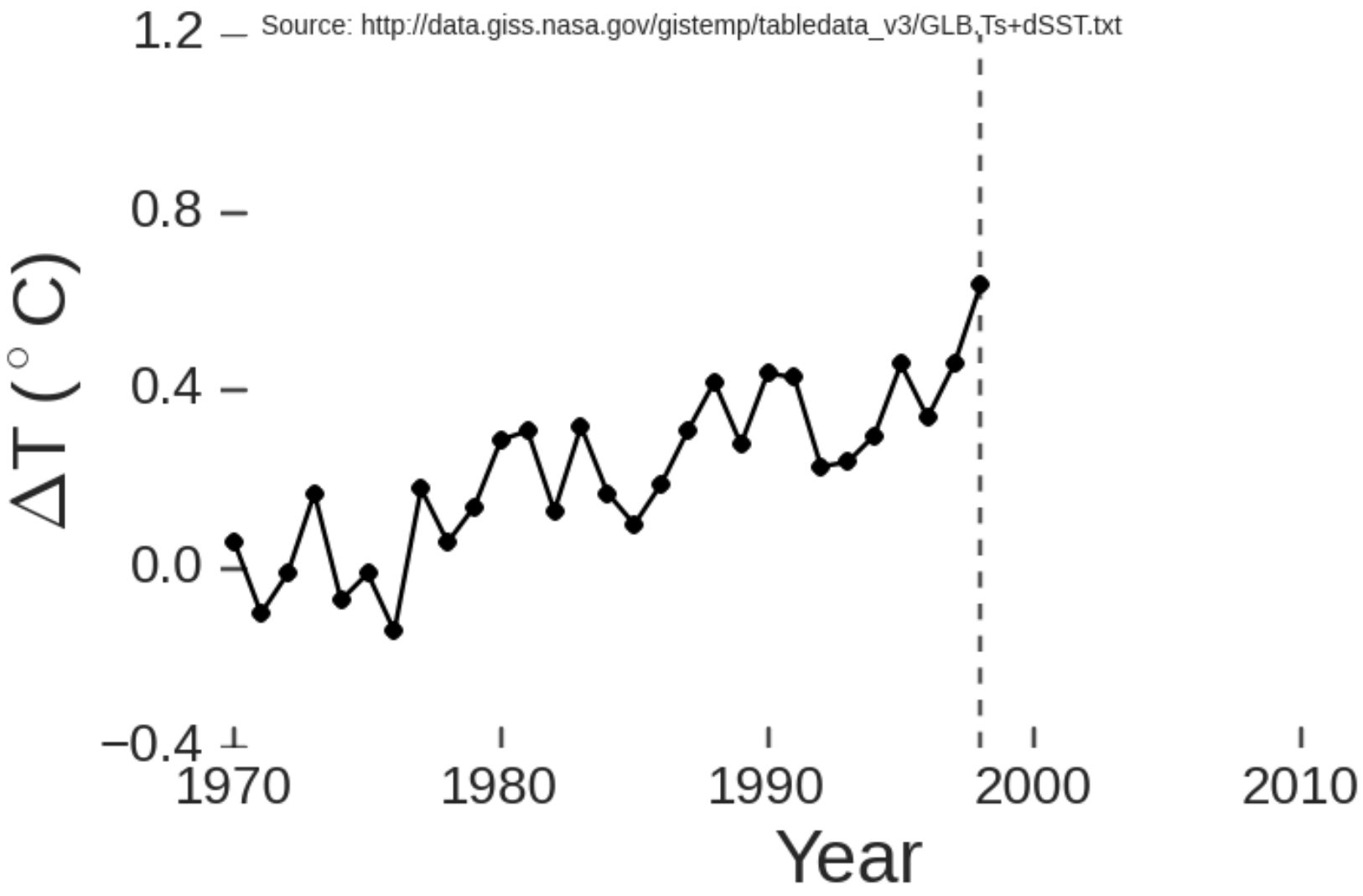
Temperature until 1998



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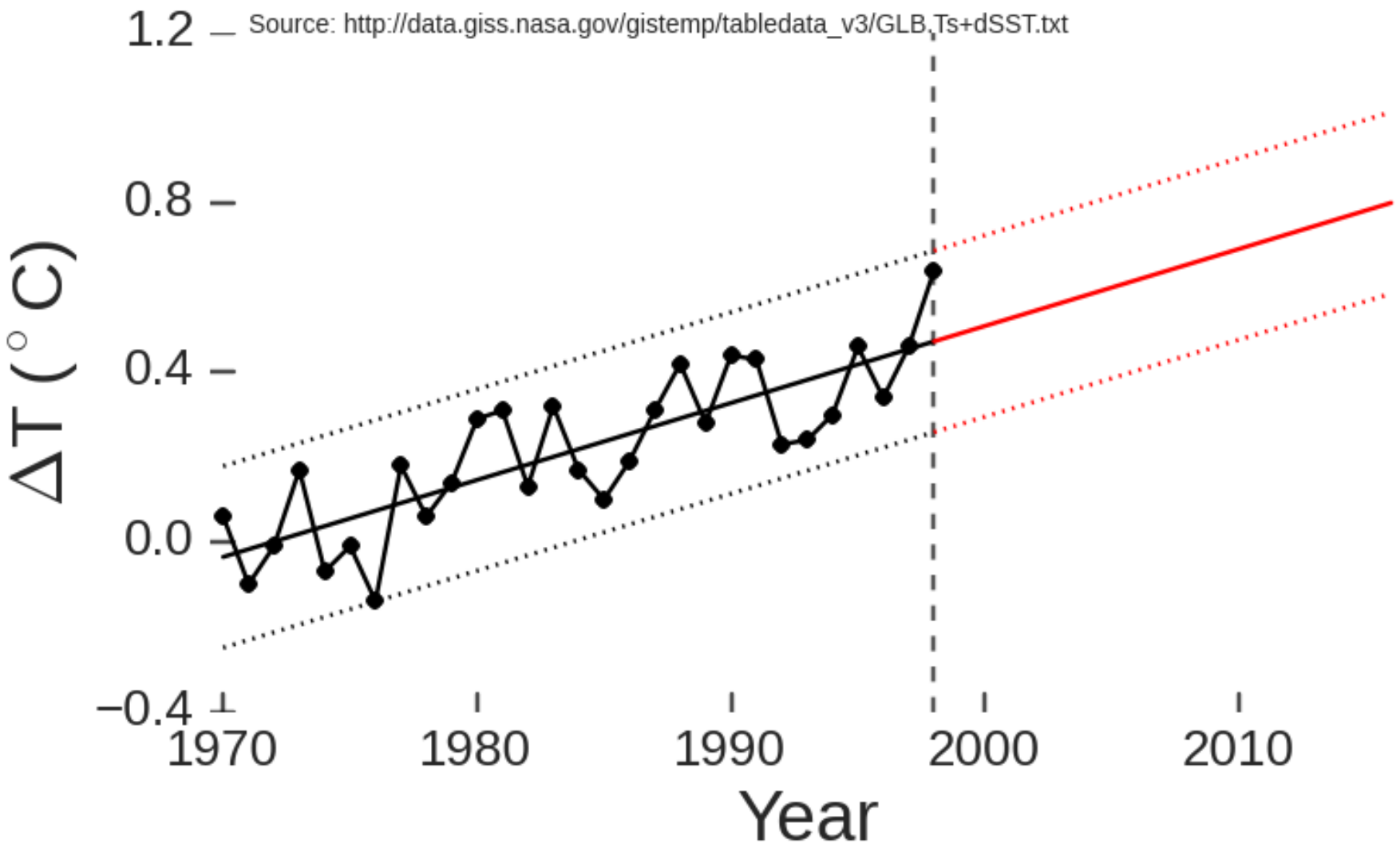
Post-1998 prediction: continued warming



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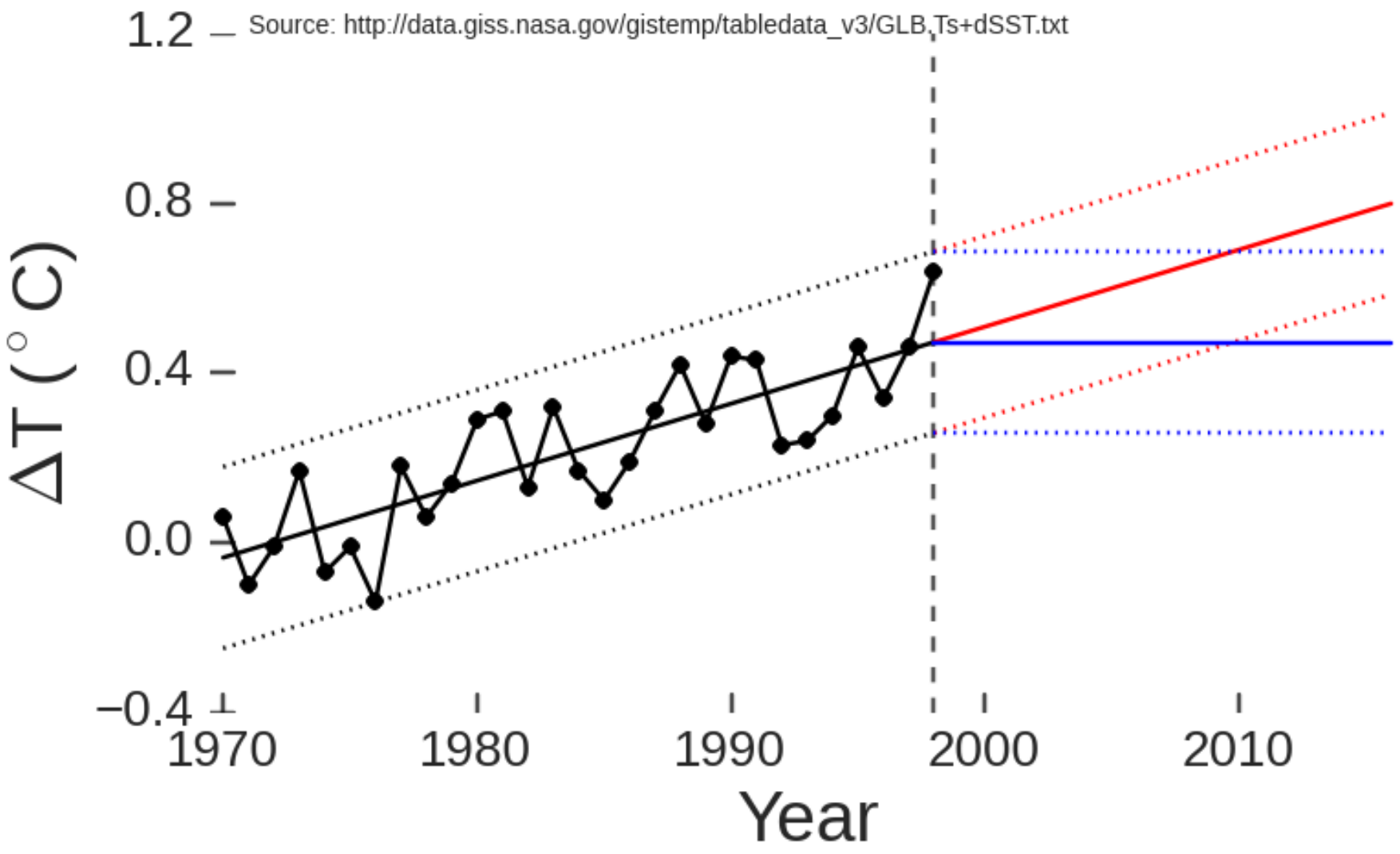
Post-1998 prediction: pause



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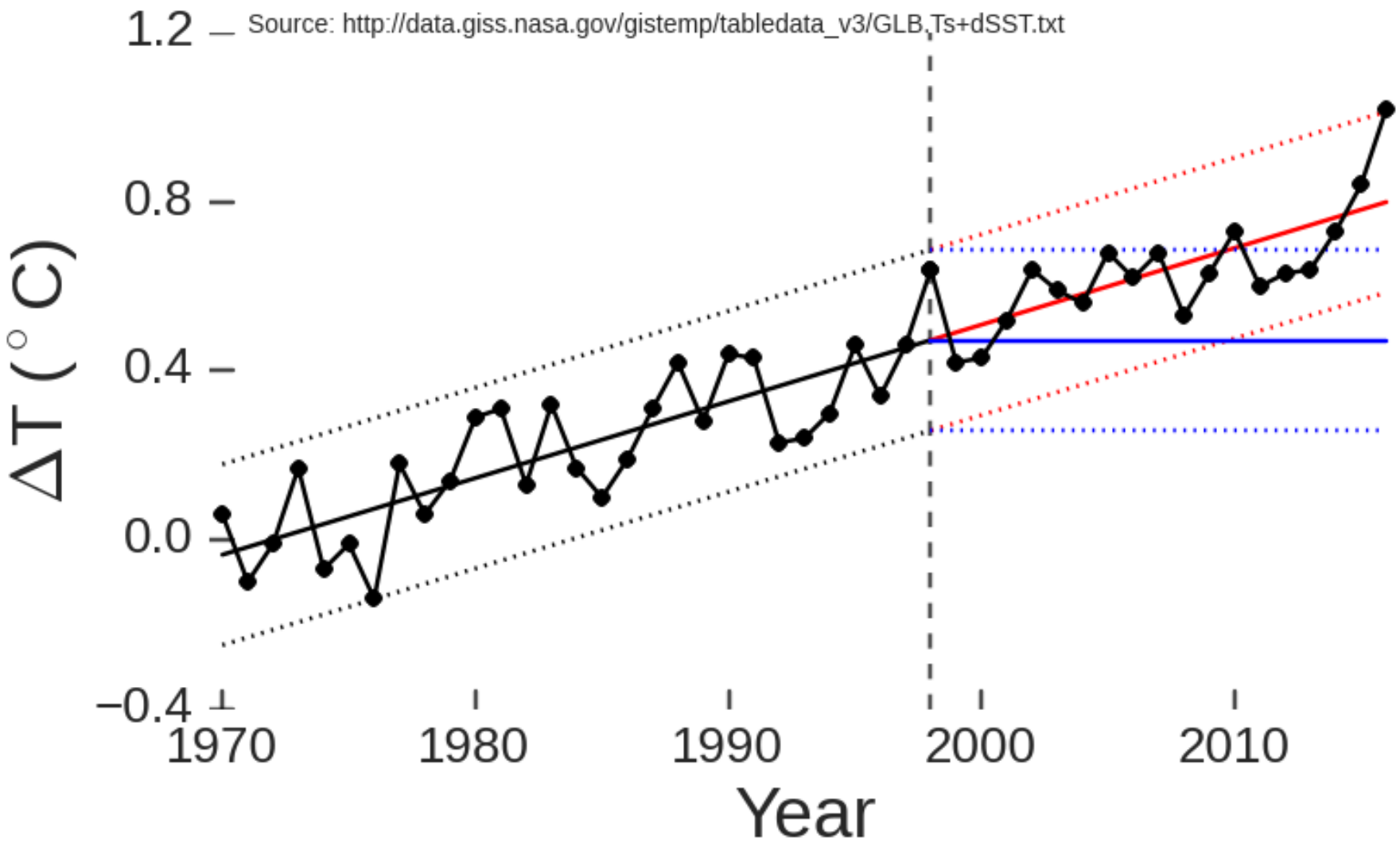
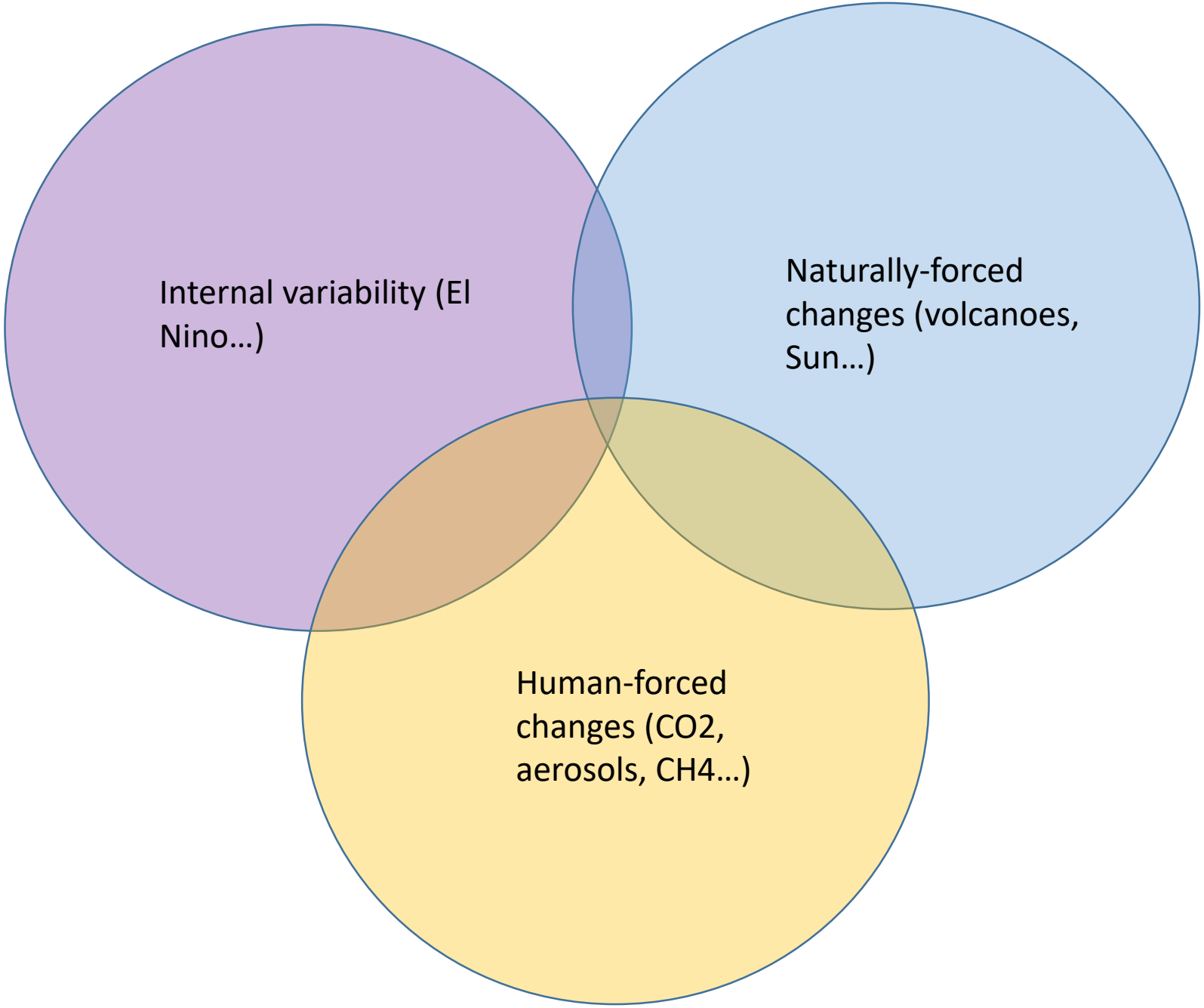
Validating predictions



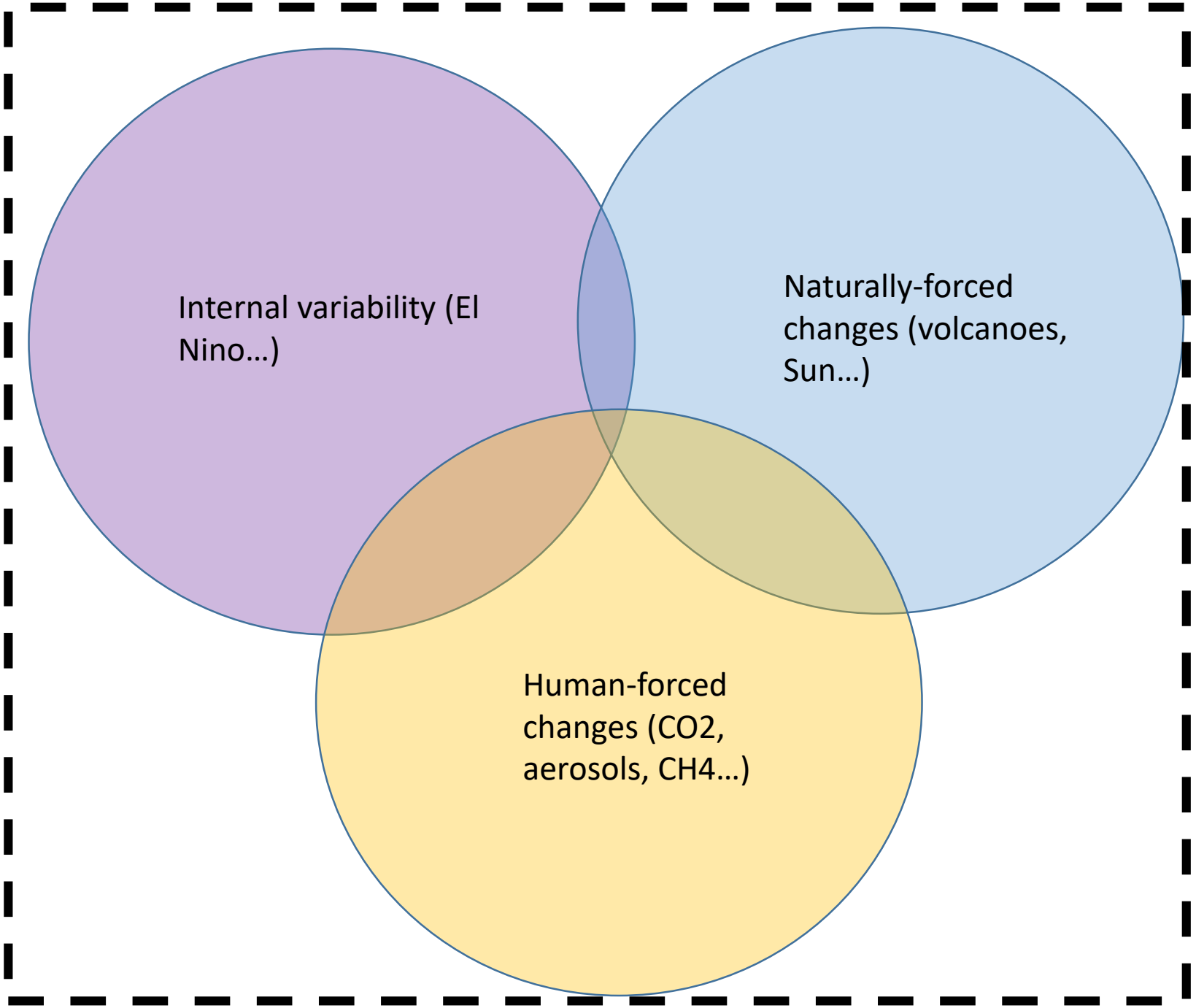
Recent warming

Global warming has been continuous since ~1970, there was no "pause/hiatus" in "global warming". Fact.*

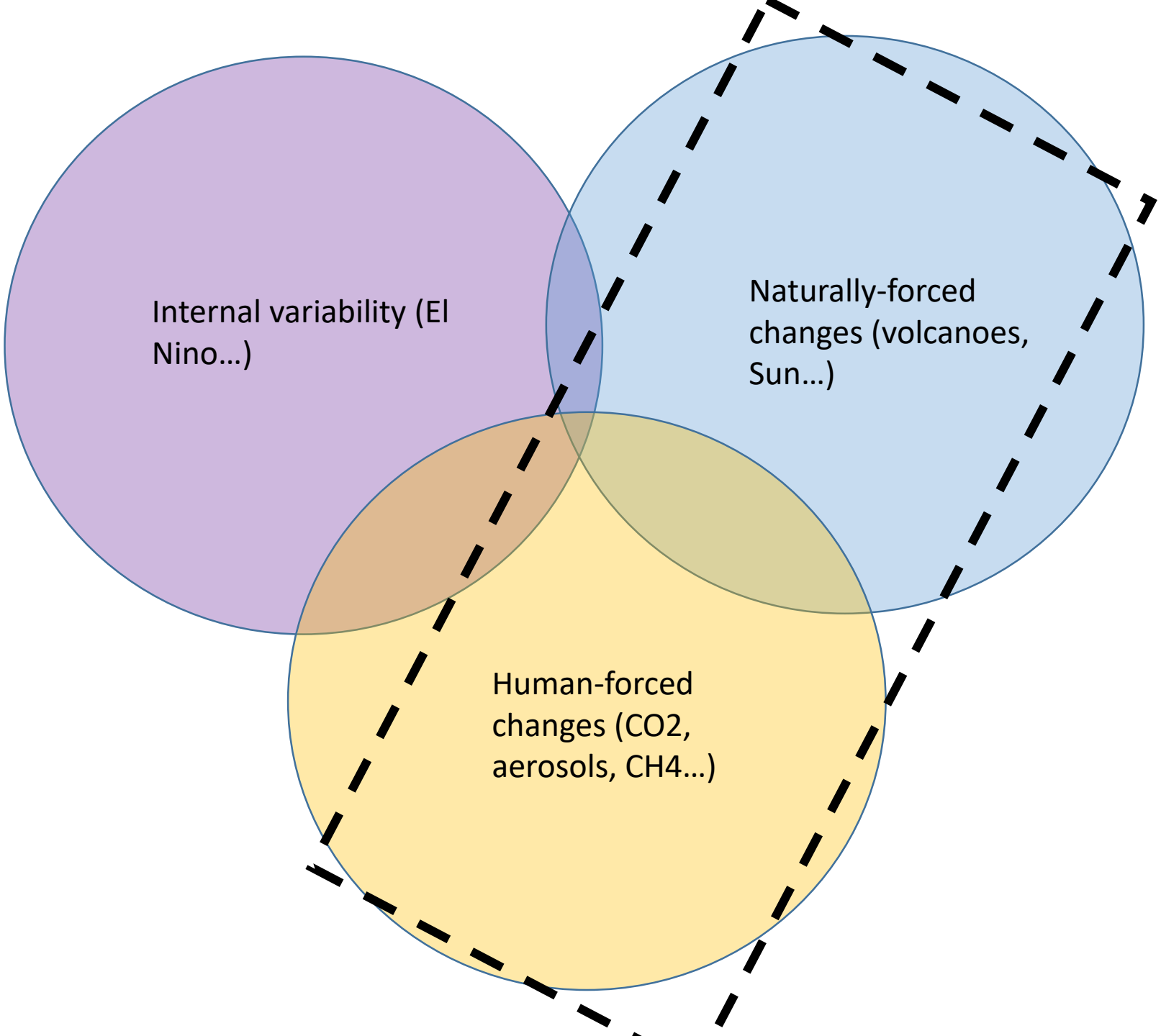
*for certain definitions of global warming


Internal variability (El Nino…)
Naturally-forced changes (volcanoes, Sun…)
Human-forced changes (CO2, aerosols, CH4…)

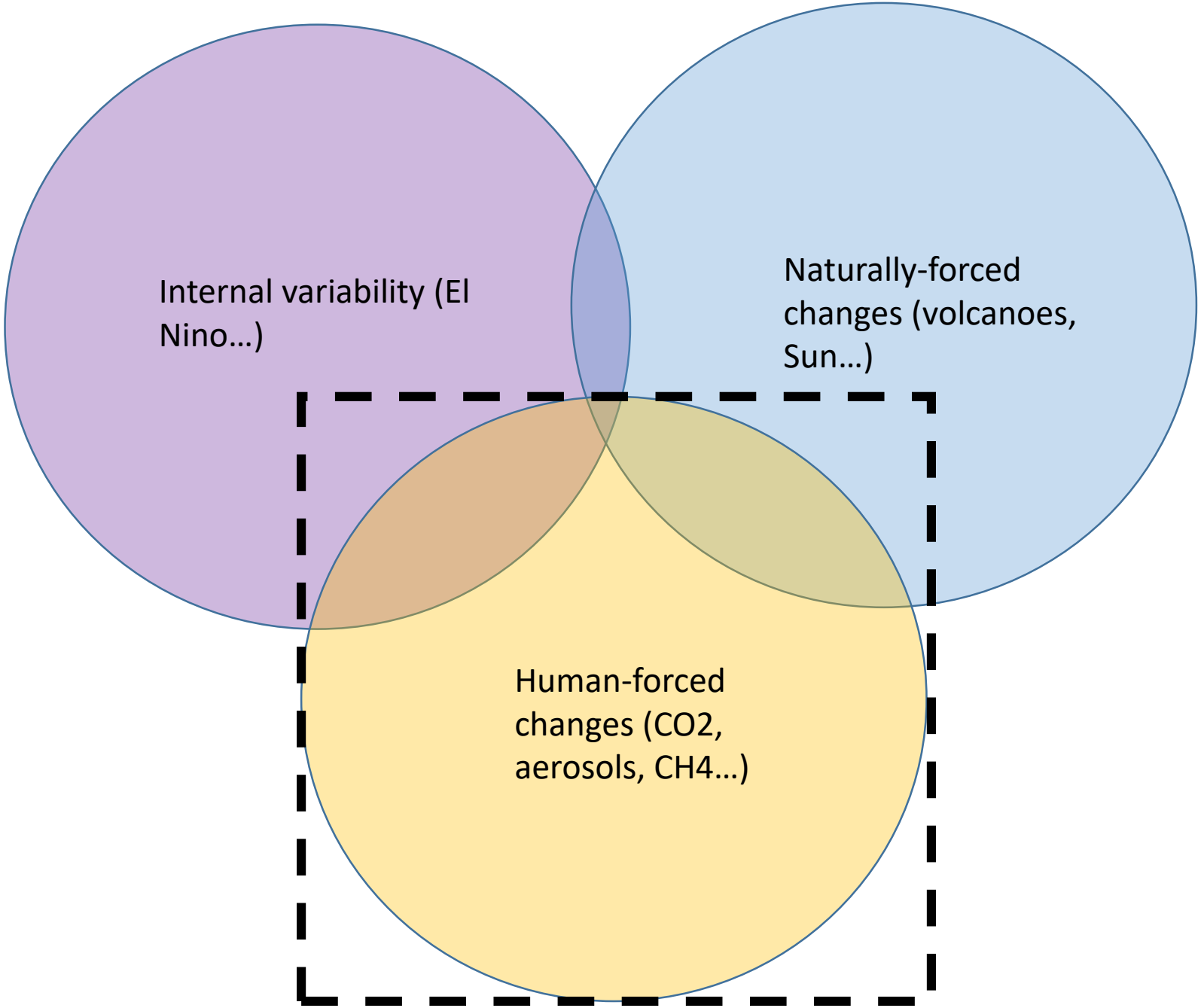
Total temperature… does “global warming” refer to this?

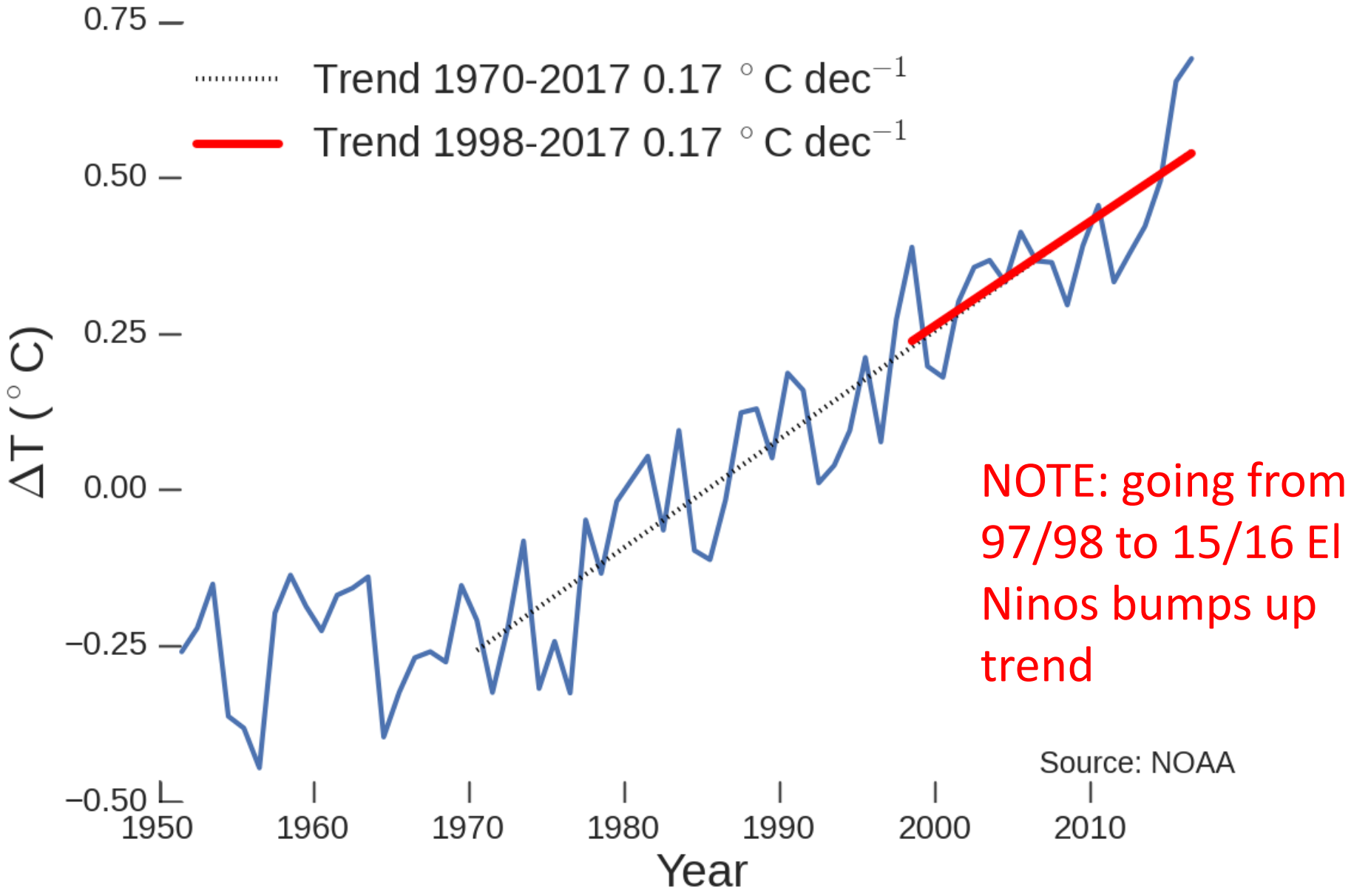


Forced temperature… does “global warming” refer to changes in this?

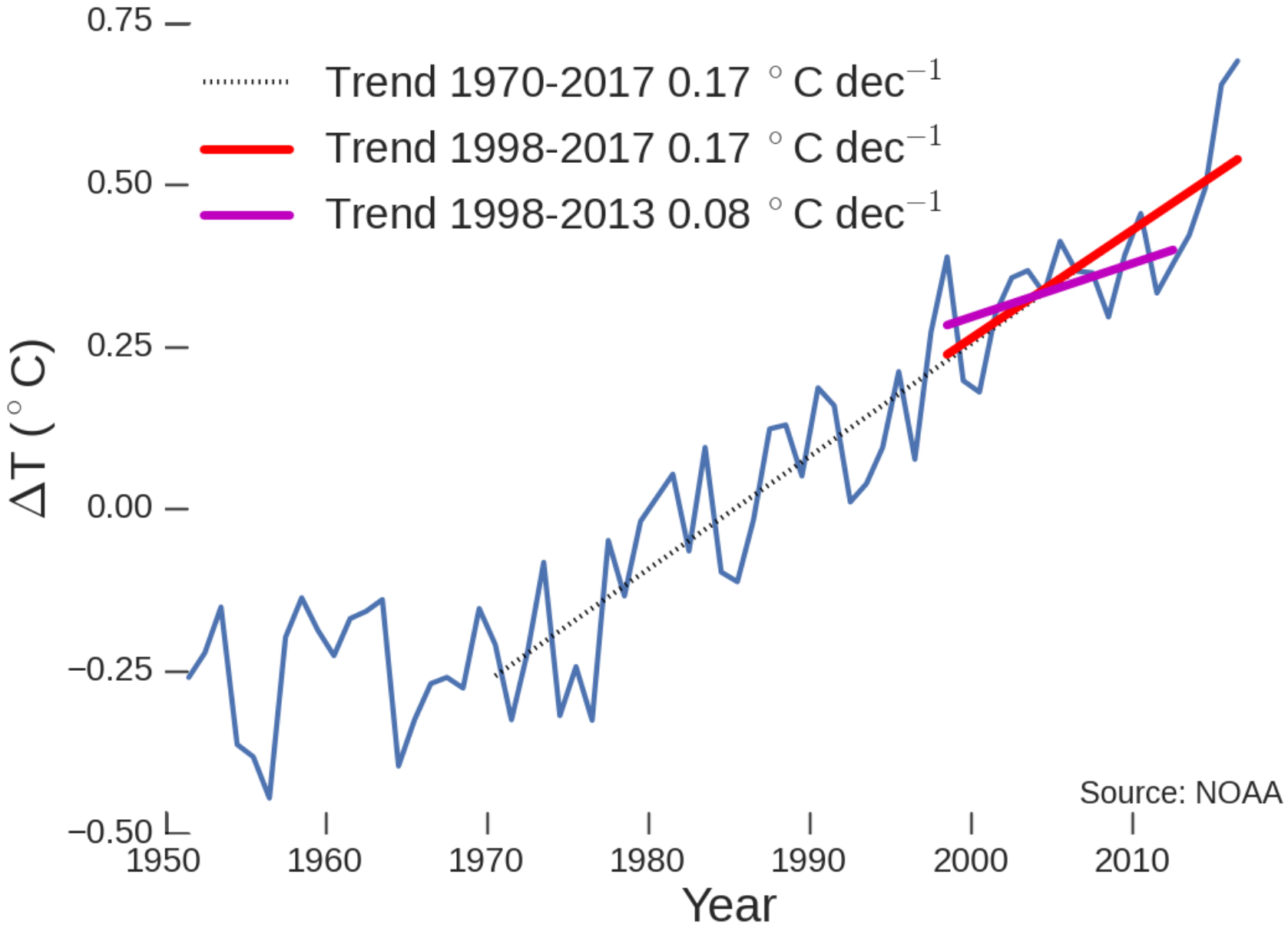


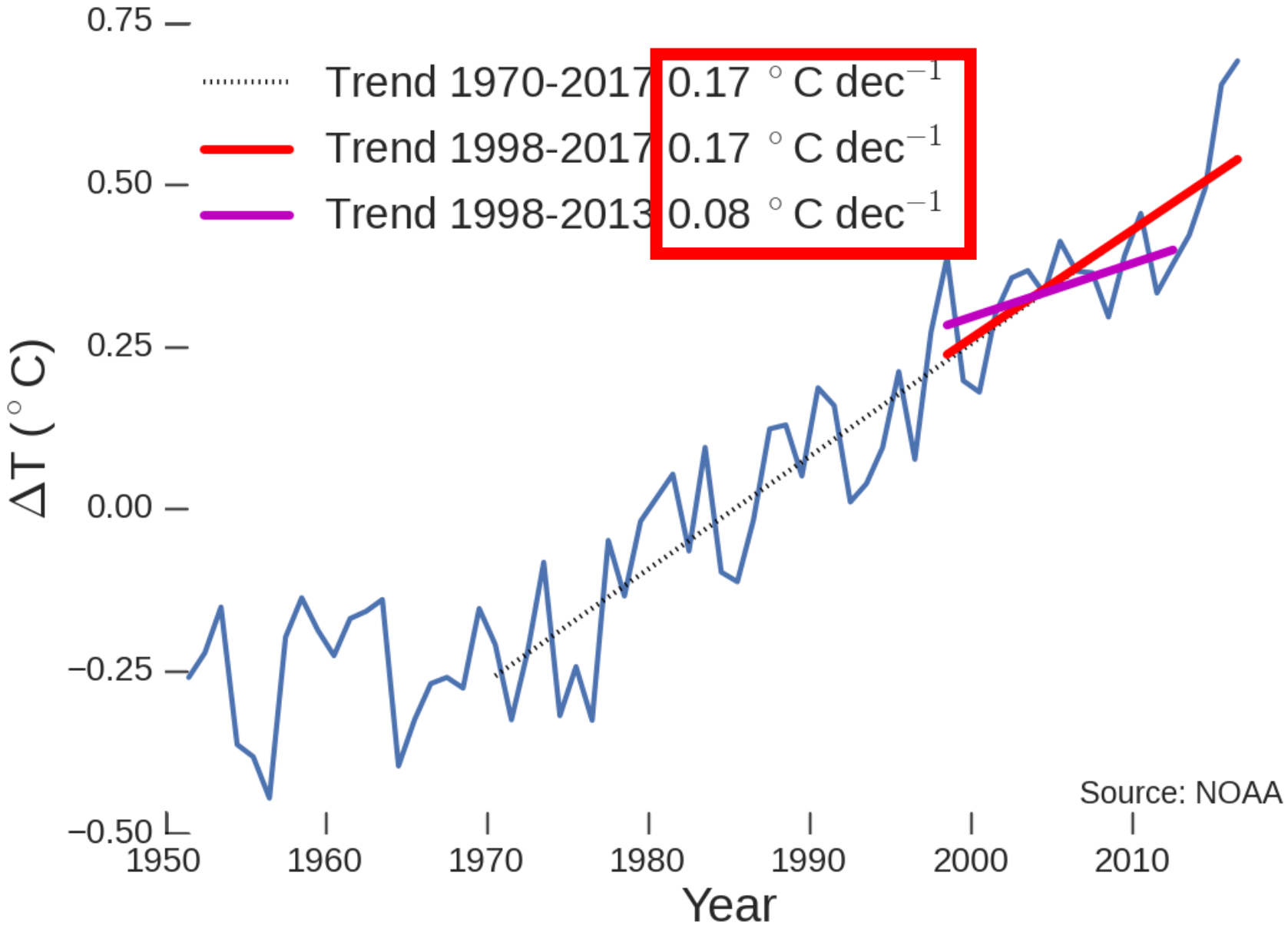
Human-forced temperature… does "global warming" refer to changes in this?





NOTE: going from 97/98 to 15/16 El Ninos bumps up trend


0.75
0.50
0.25
0.00
−0.25
−0.50
ΔT (°C)
Trend 1970-2017 0.17 °C dec^{-1}
Trend 1998-2017 0.17 °C dec^{-1}
Trend 1998-2013 0.08 °C dec^{-1}
Source: NOAA
1950
1960
1970
1980
1990
2000
2010
Year


0.75
0.50
0.25
0.00
−0.25
−0.50
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Trend 1970-2017 0.17 °C dec^{-1}
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1950
1960
1970
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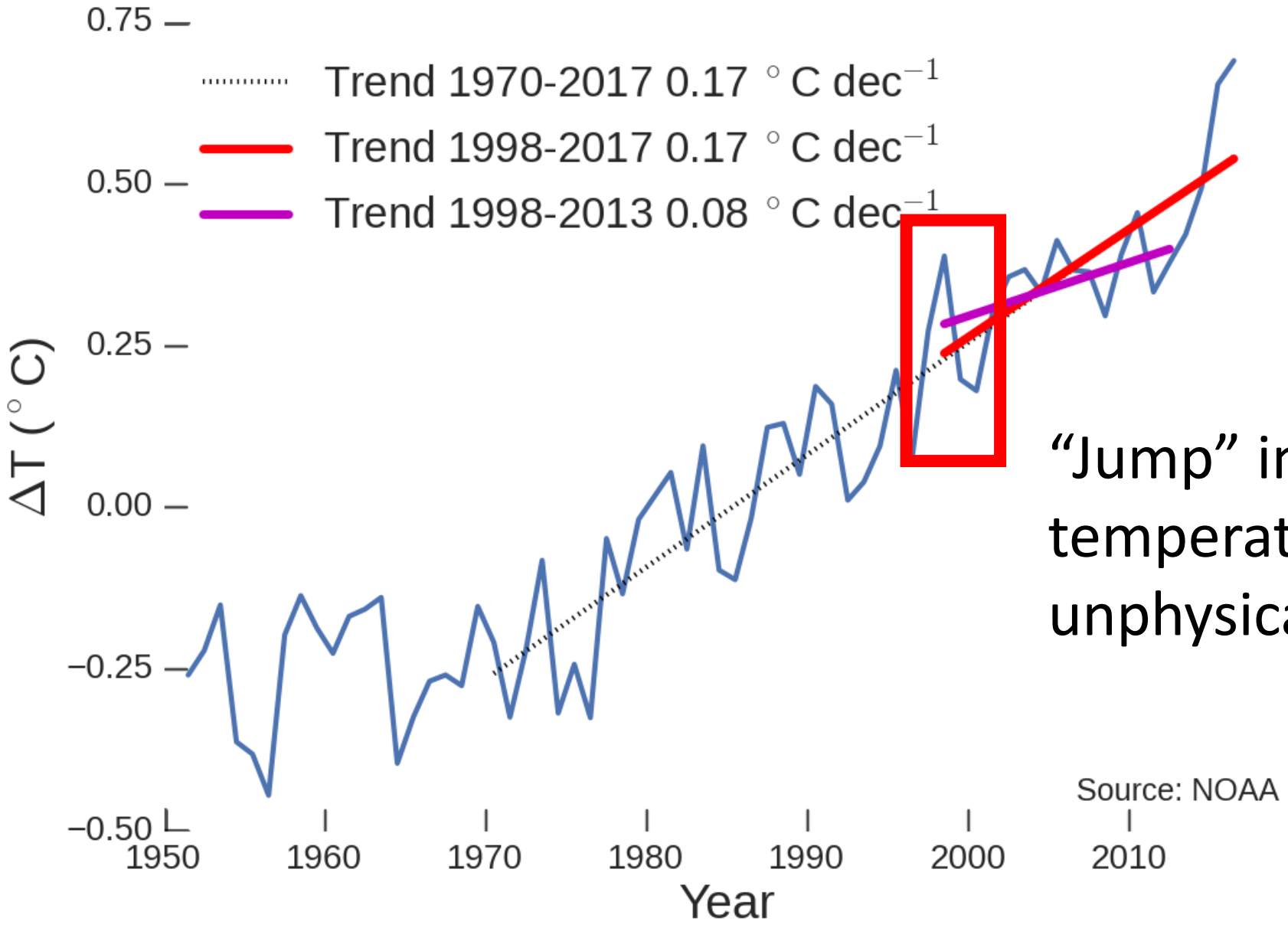
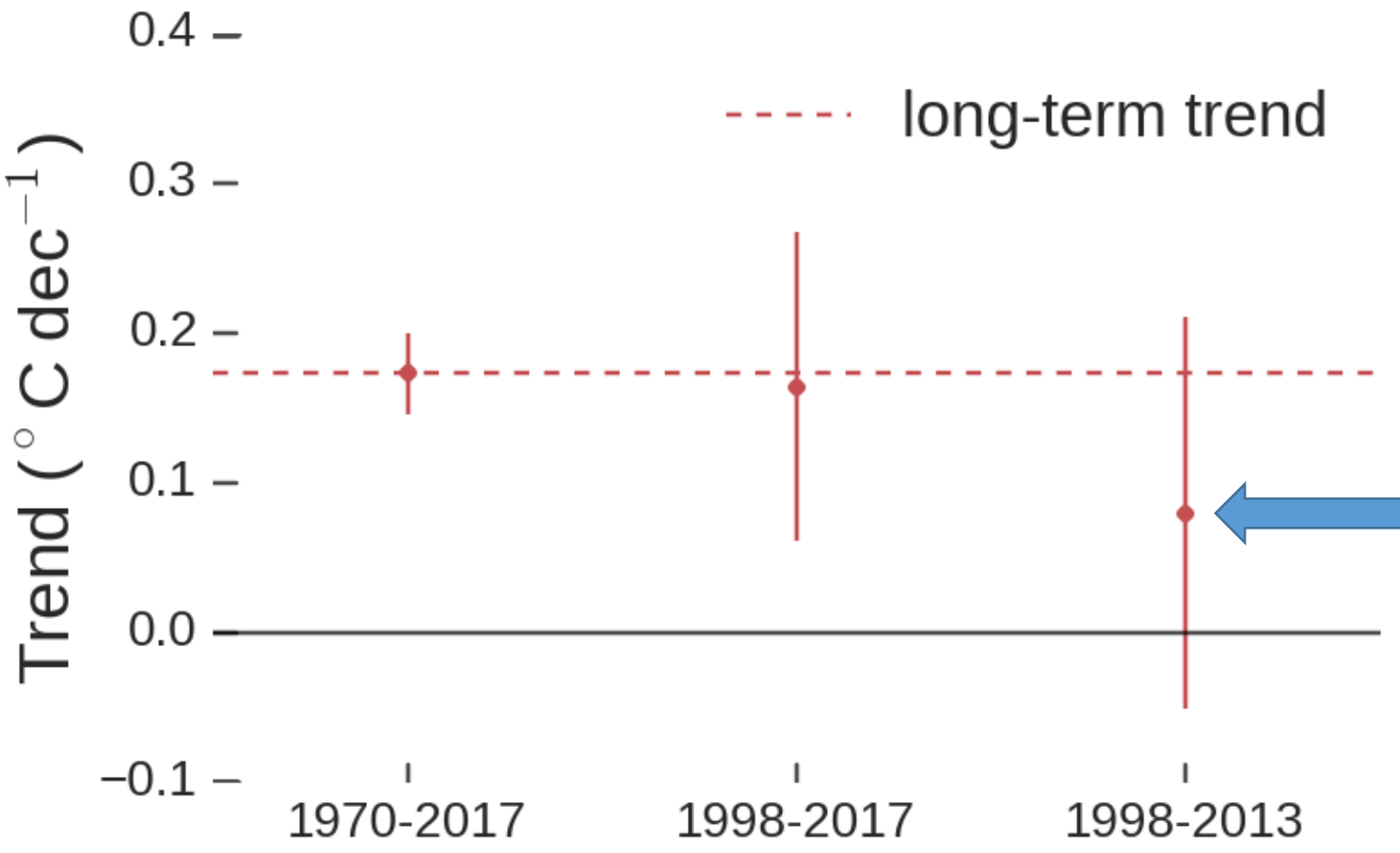
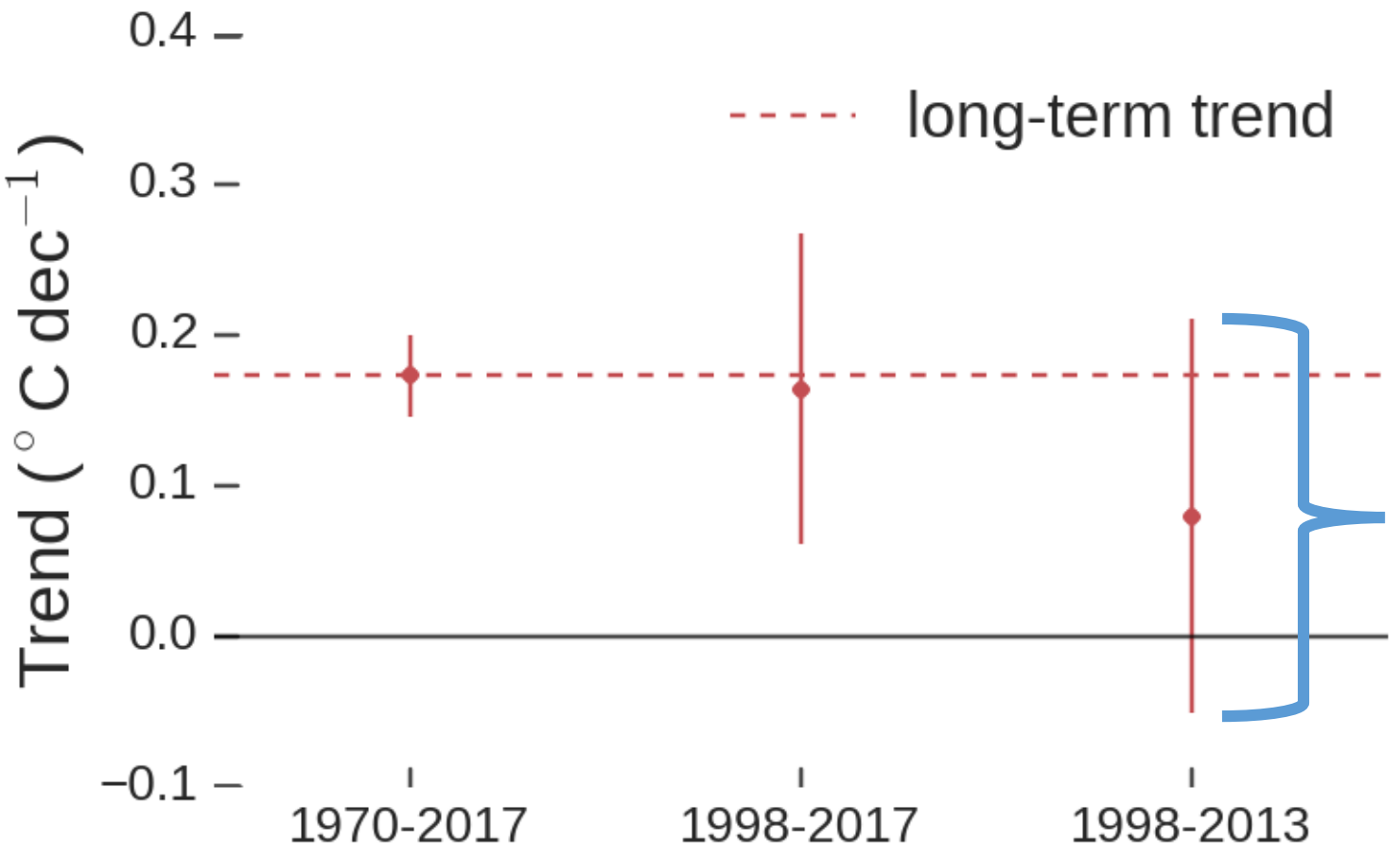
2010
Year



"Jump" in temperatures – unphysical?



Interpretation 1:
Look at this, it's lower!



Interpretation 2: Look at this, you can't tell it's lower!

- Stats fits assume something about what is “signal” vs “noise”
- For 1998—2013 fit, temperature “jumps” at 1998
- We know 97/98 was an El Nino
- We also know the pre-1998 data, so we have prior information on the intercept of any post-1998 fit… LOWESS is a technique that includes this information and it looks like this:

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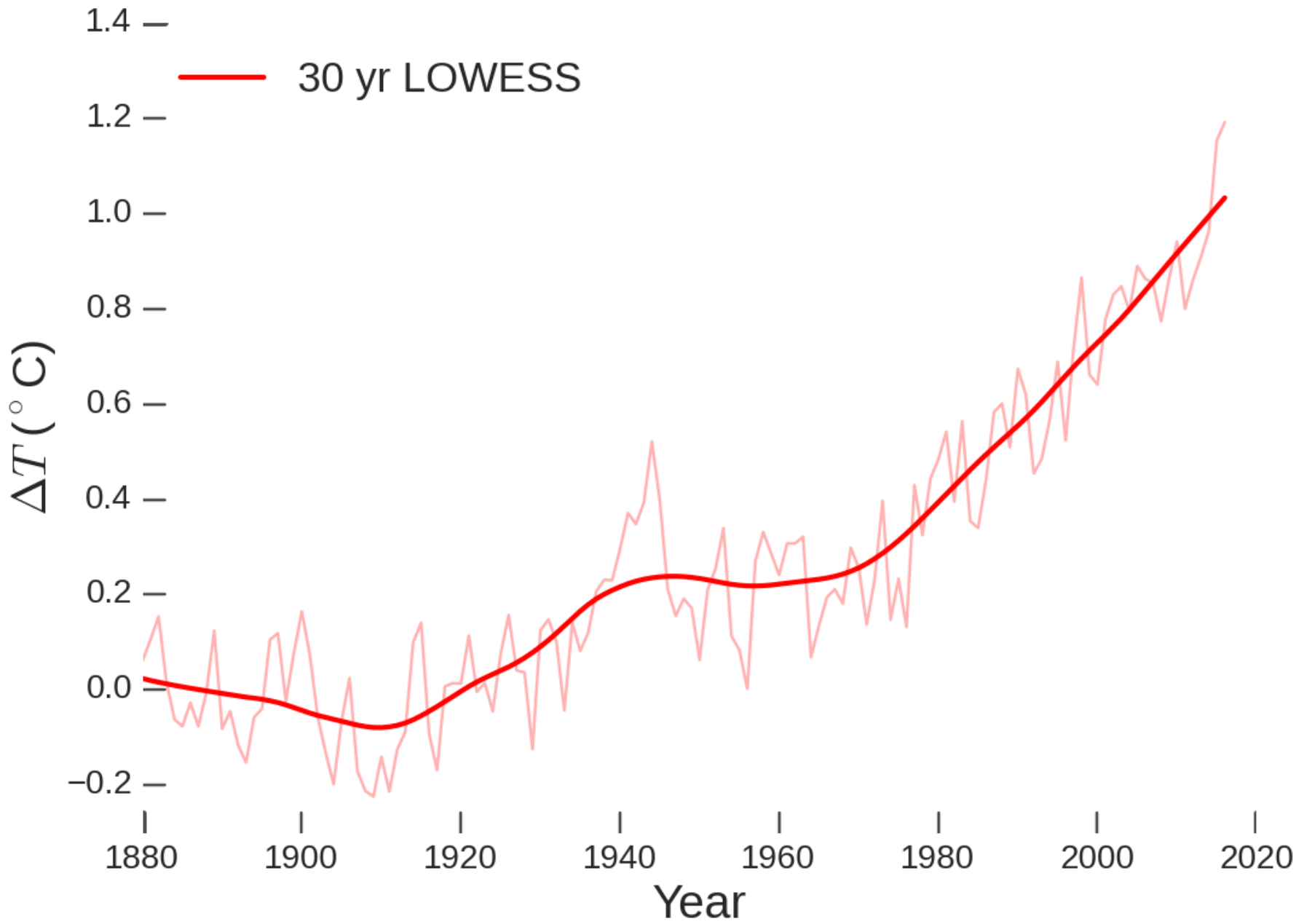

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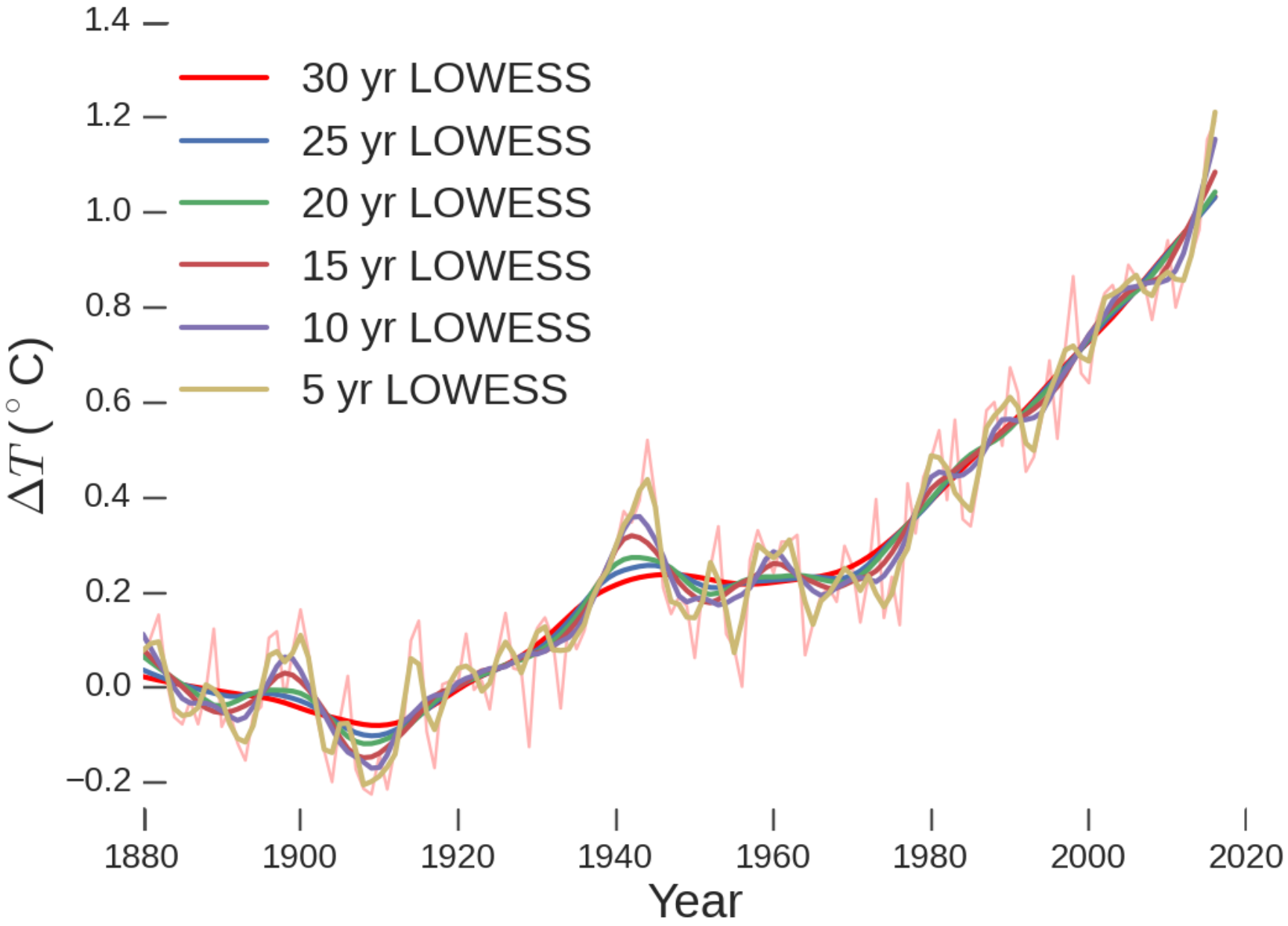

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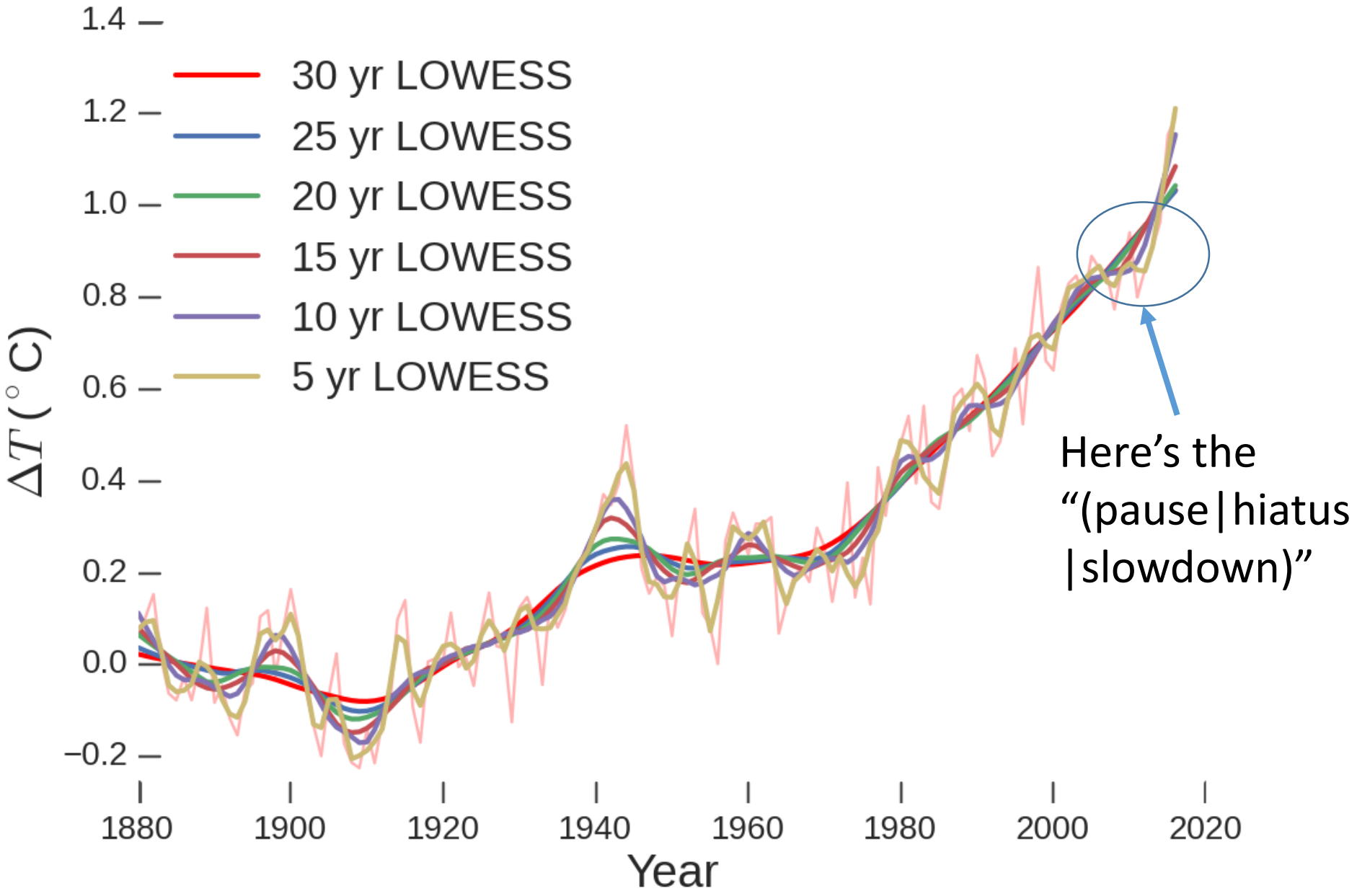

- What happens when we try to include some physical knowledge?
- Begin with stats, let’s do real physics later

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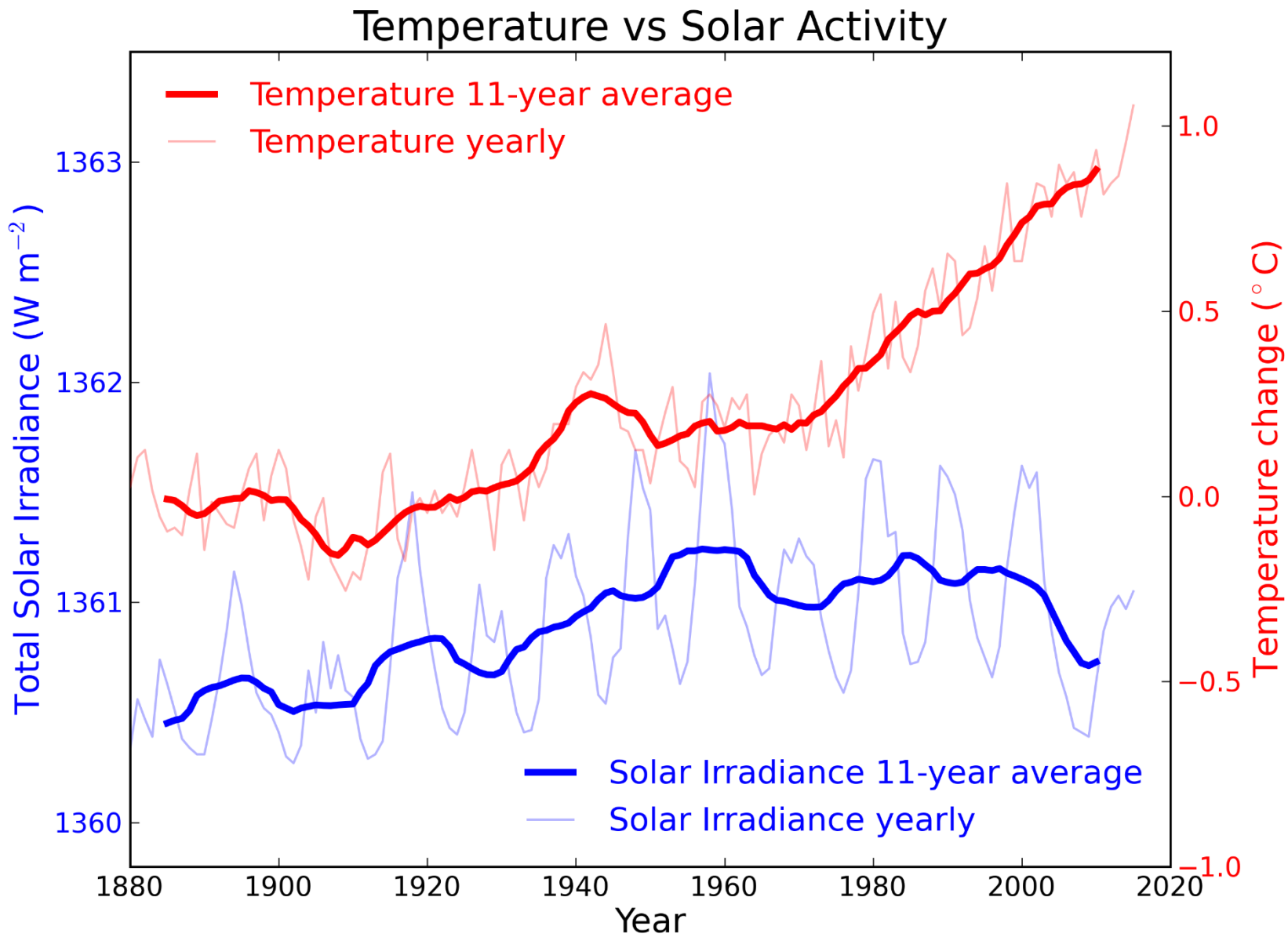

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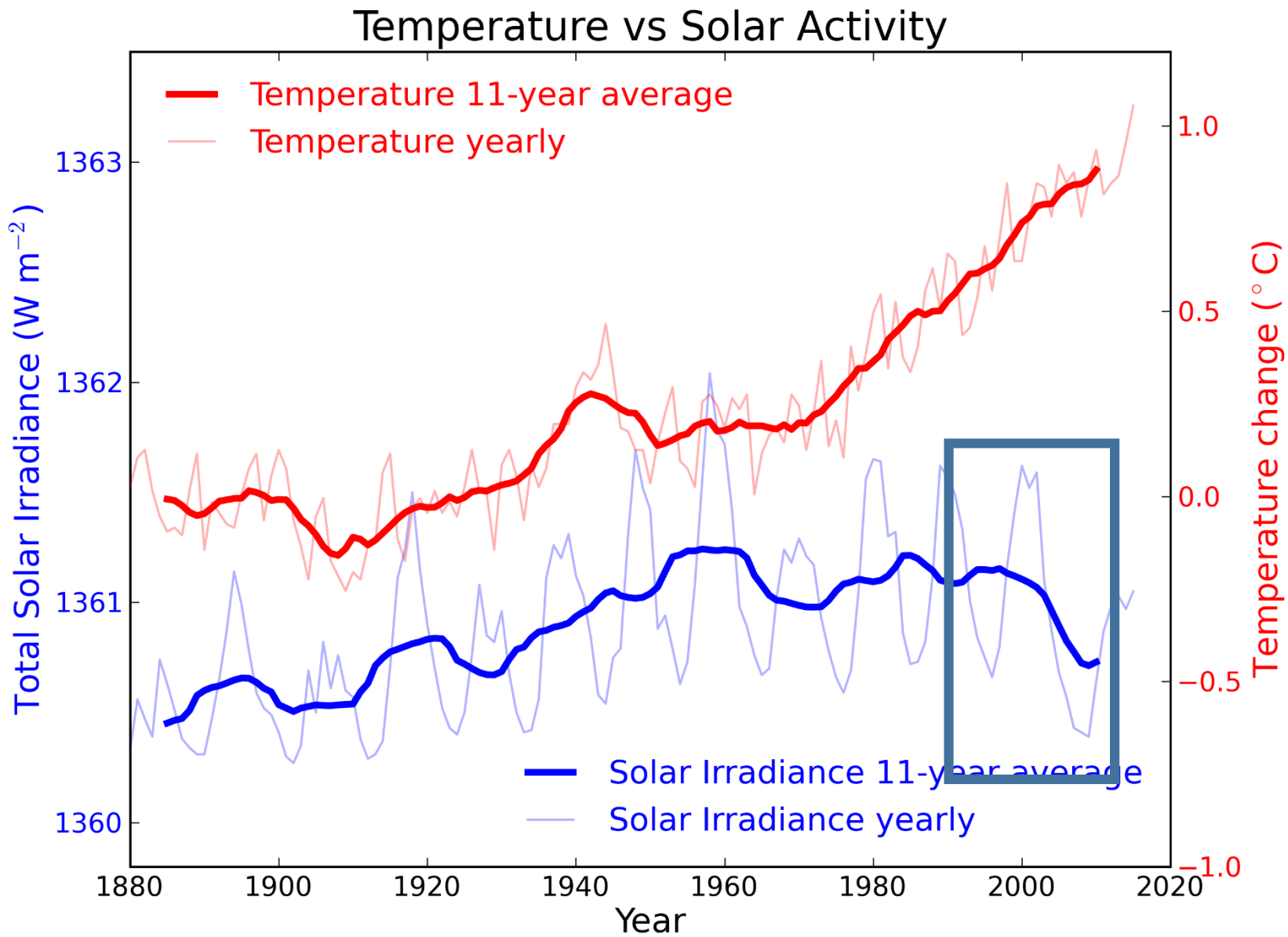

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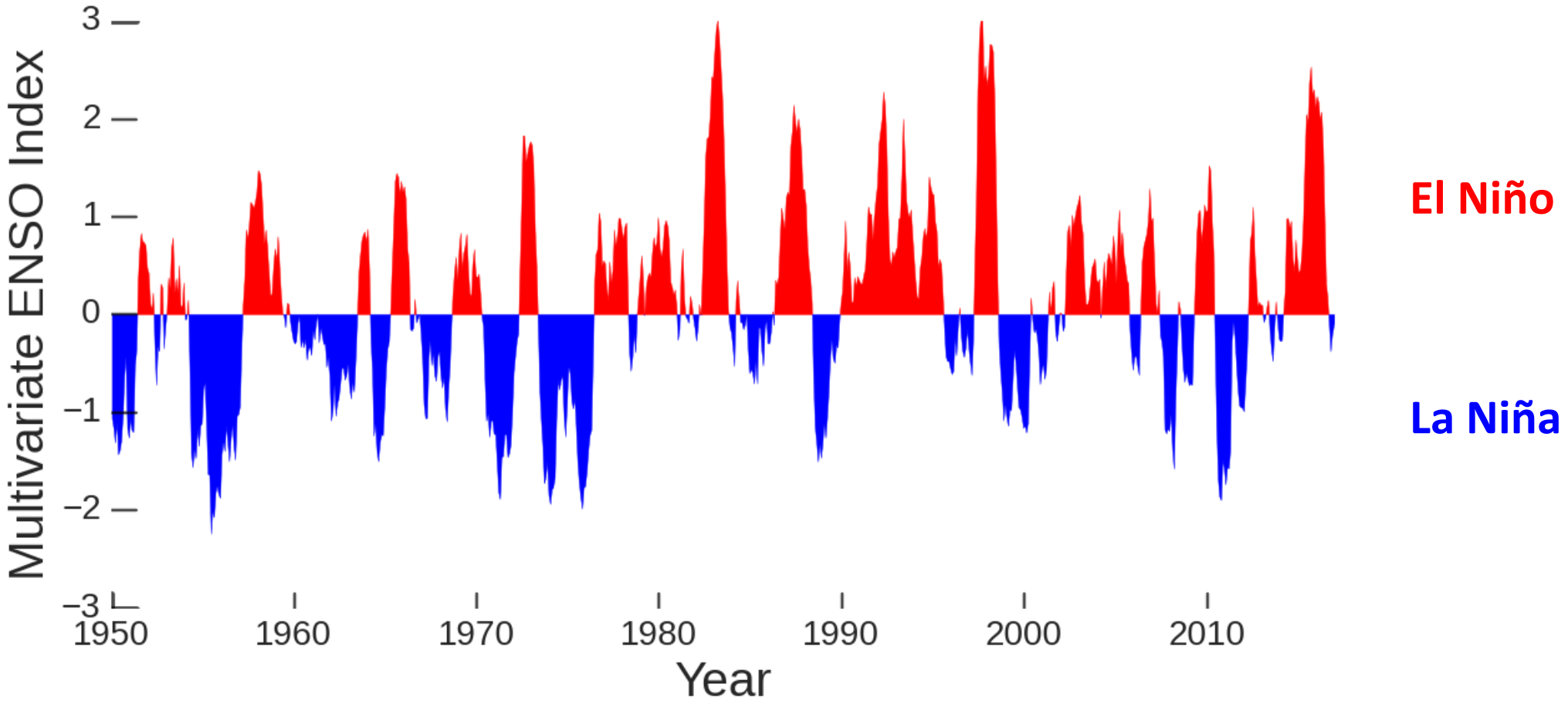

Modified from Walter & Timlin (2011) doi: 10.1002/joc.2336

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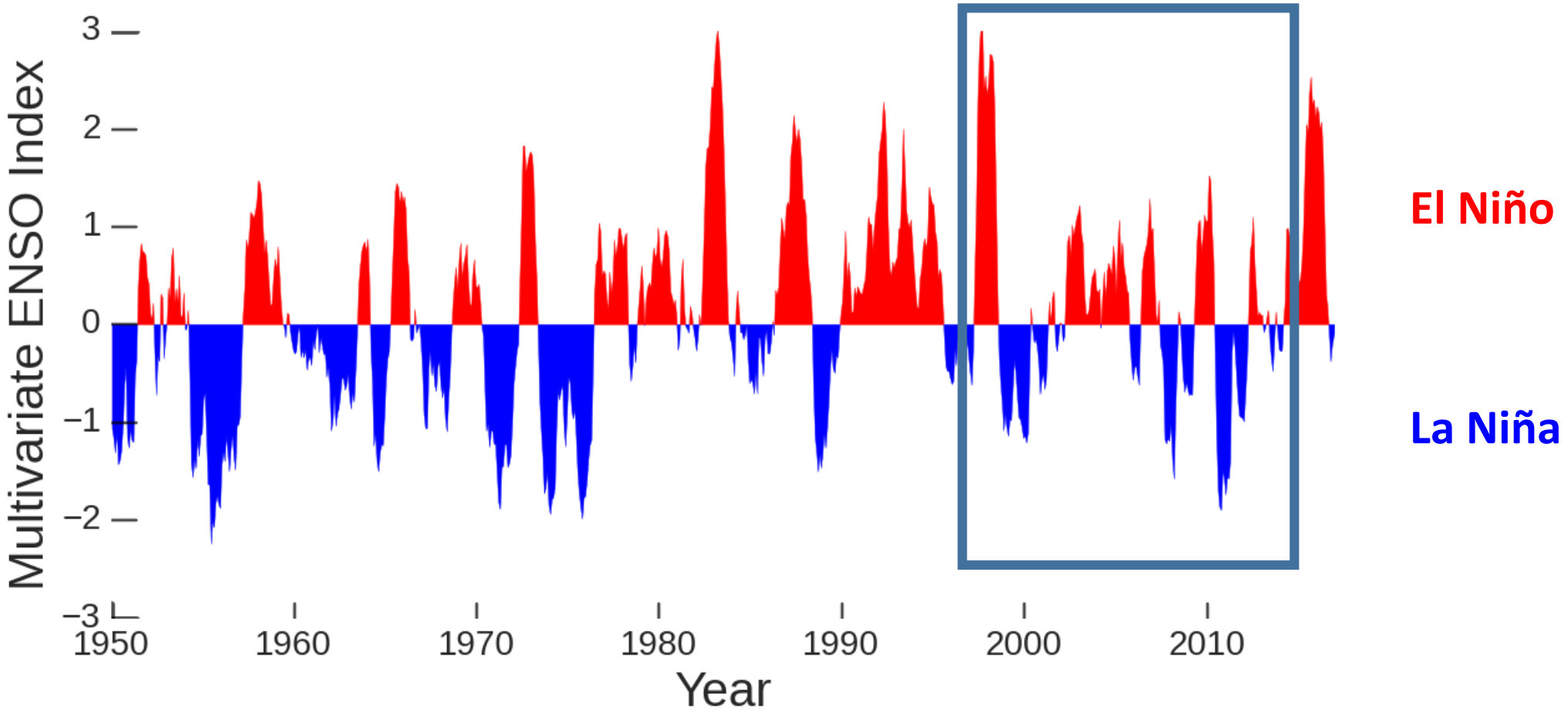
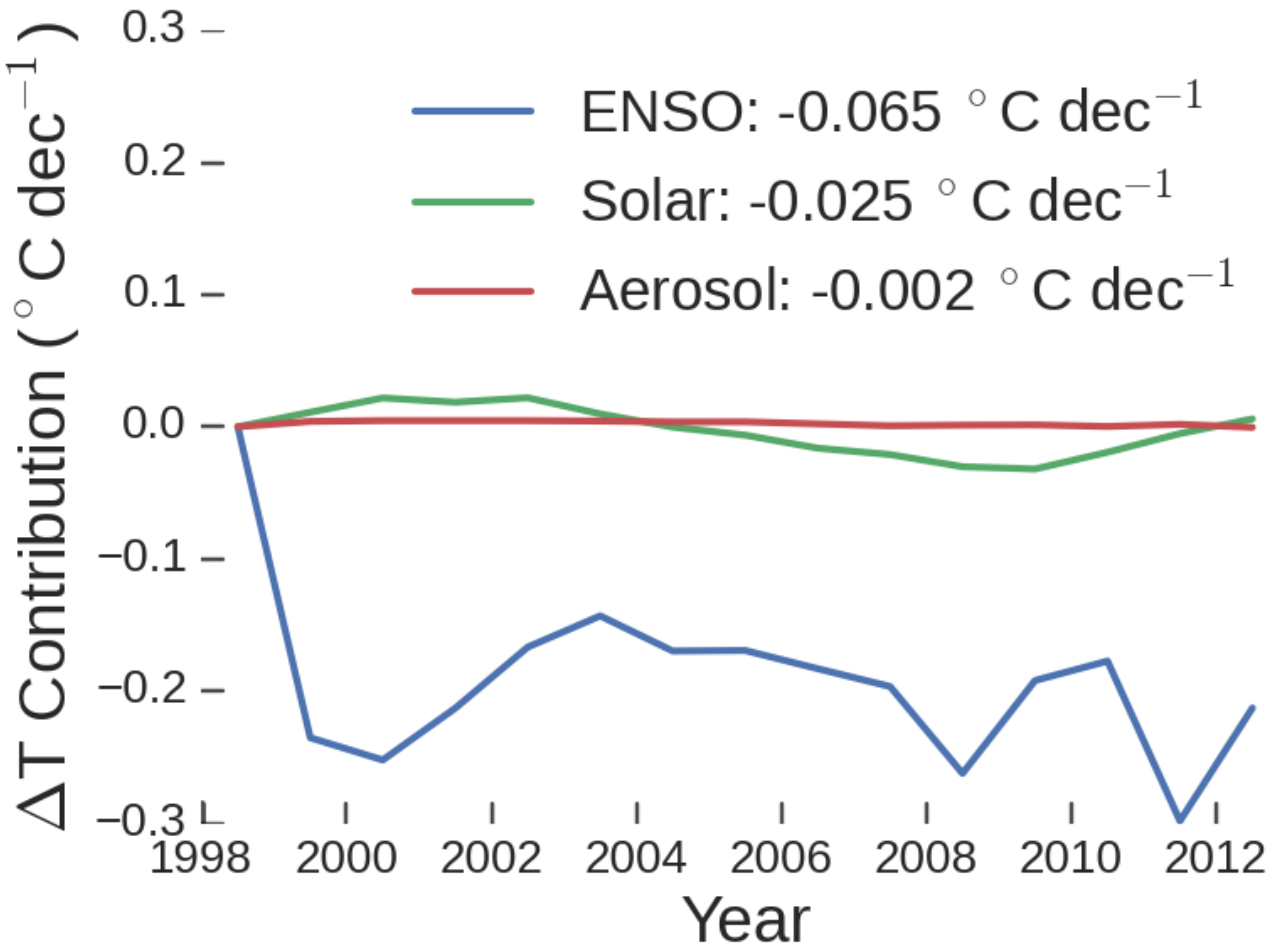


El Niño

La Niña

Modified from Walter & Timlin (2011) doi: 10.1002/joc.2336

Foster & Rahmstorf (2011) used multi-variate regression to isolate temperature effects from El Nino, Solar, volcanoes…



Modified from Foster & Rahmstorf (2011) doi: 10.1088/1748-9326/6/4/044022

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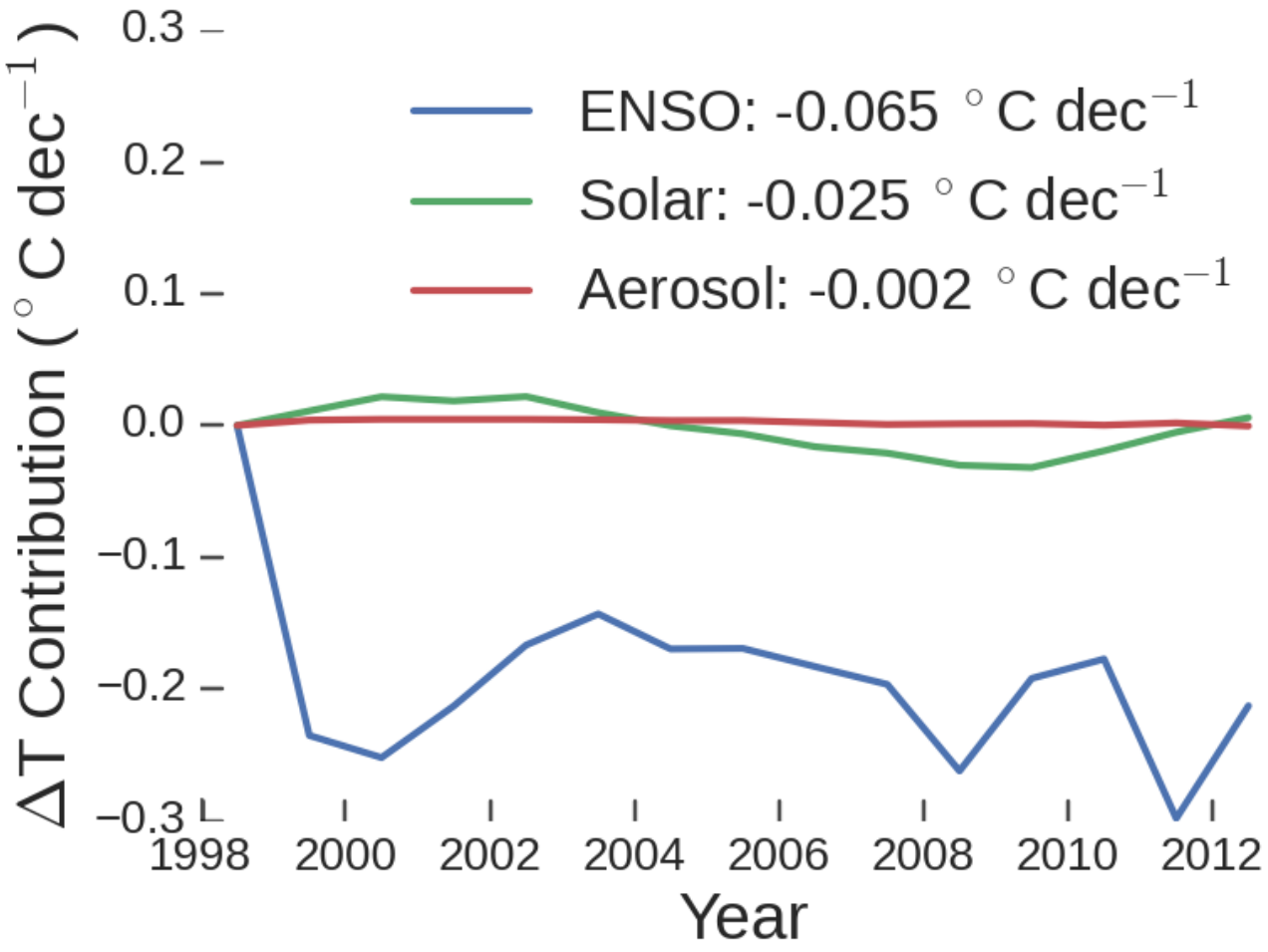
ENSO + solar trend effect is large enough to explain *all* difference between observed trend and continued warming trend



Modified from Foster & Rahmstorf (2011) doi: 10.1088/1748-9326/6/4/044022

…it certainly looks like ENSO (or something correlated with it) has a lot to do with recent temperature evolution!

Let’s look at some physics

Physics *didn't* say global warming would be constant since 1970

So far I showed evidence against a "pause" or "hiatus"

Our job is to work out the processes that explain as much as possible of what's going on and then use those to make useful, testable projections for the future

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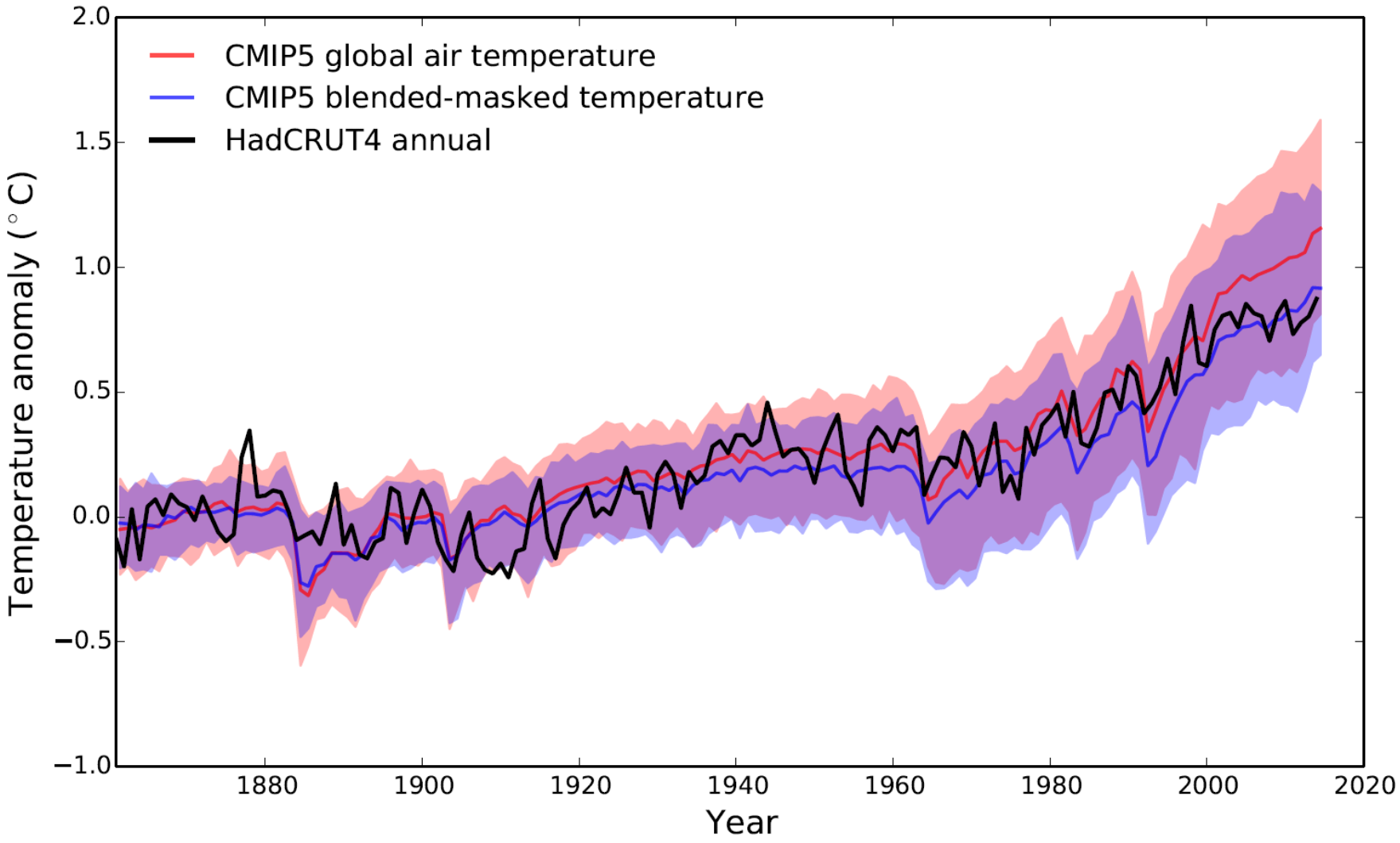
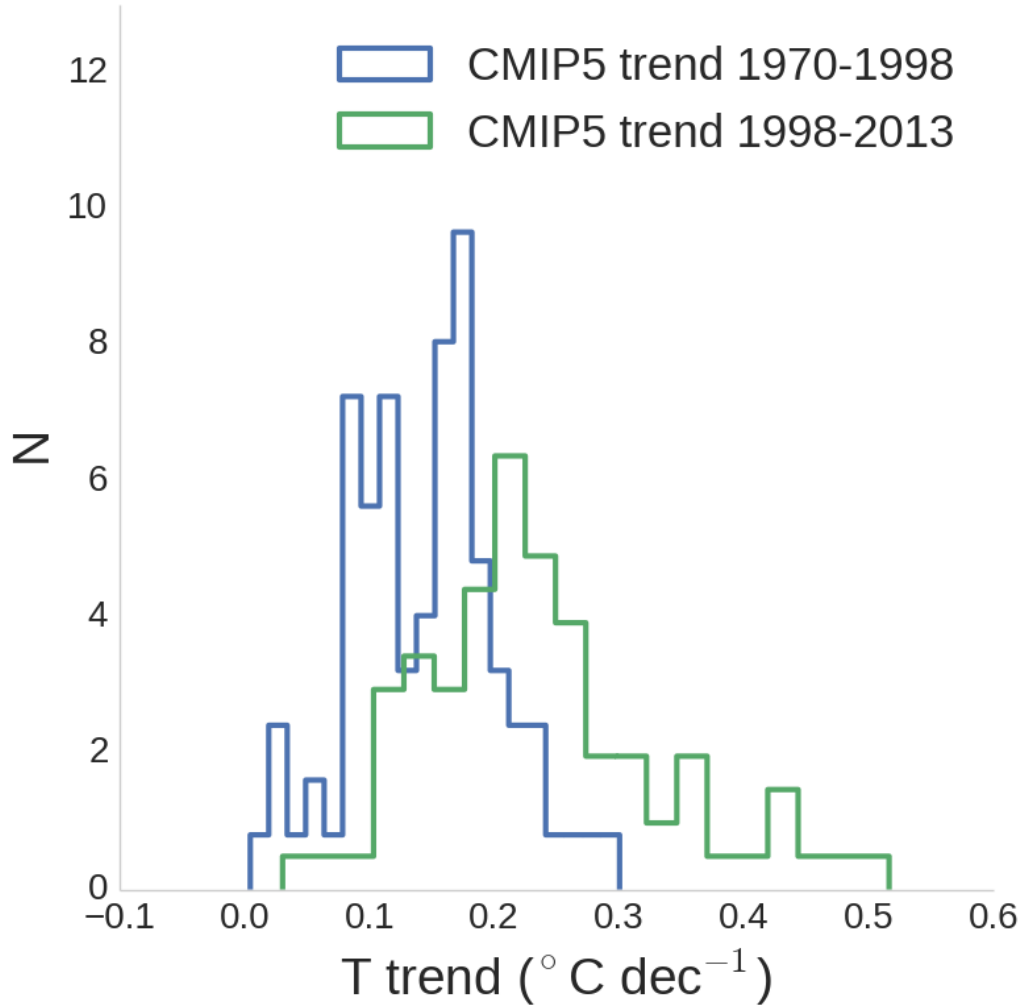
Black = observations
Red = climate model global air temperature
Blue = climate model output sampled like observations




CMIP5 trend 1970-1998
CMIP5 trend 1998-2013
N
0
2
4
6
8
10
12
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
T trend (° C dec^{-1})

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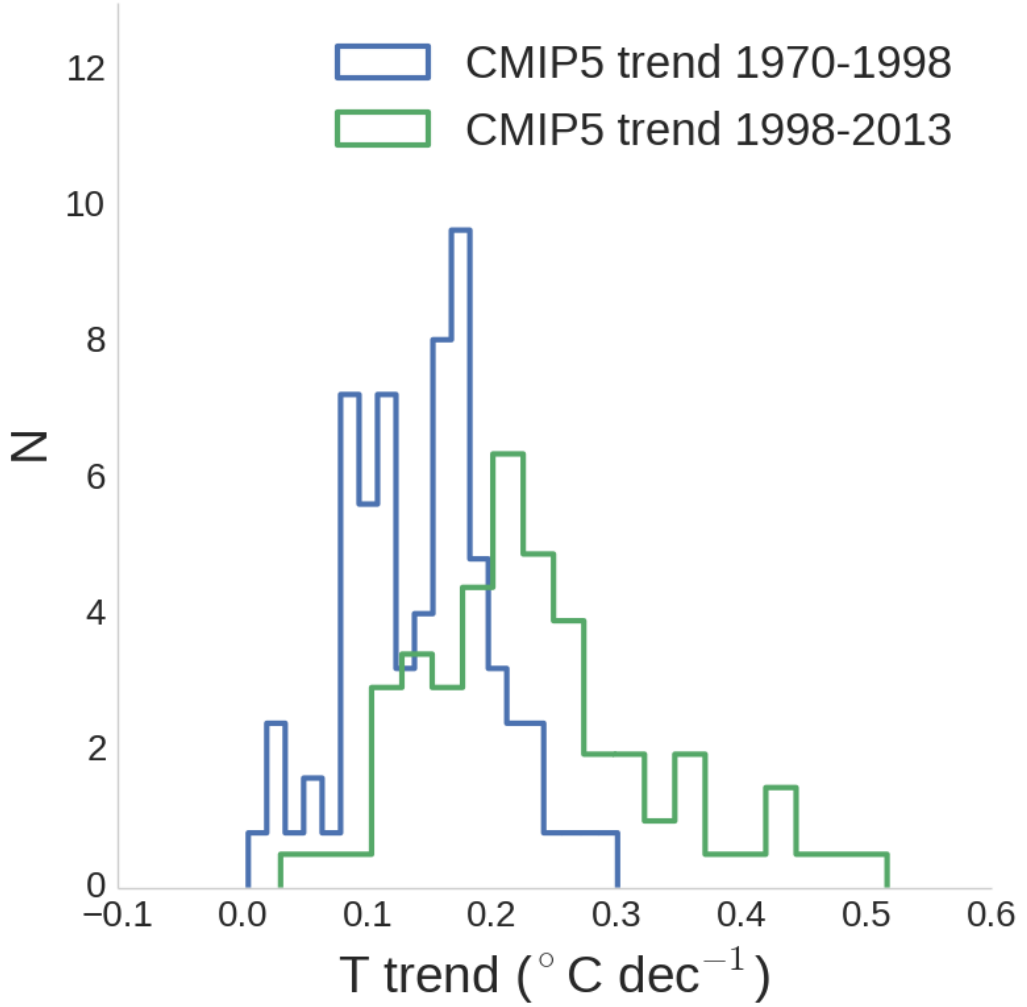
No evidence of a change in obs trend, but 80 % of CMIP5 sims show faster warming over 1998—2013 vs 1970—1998



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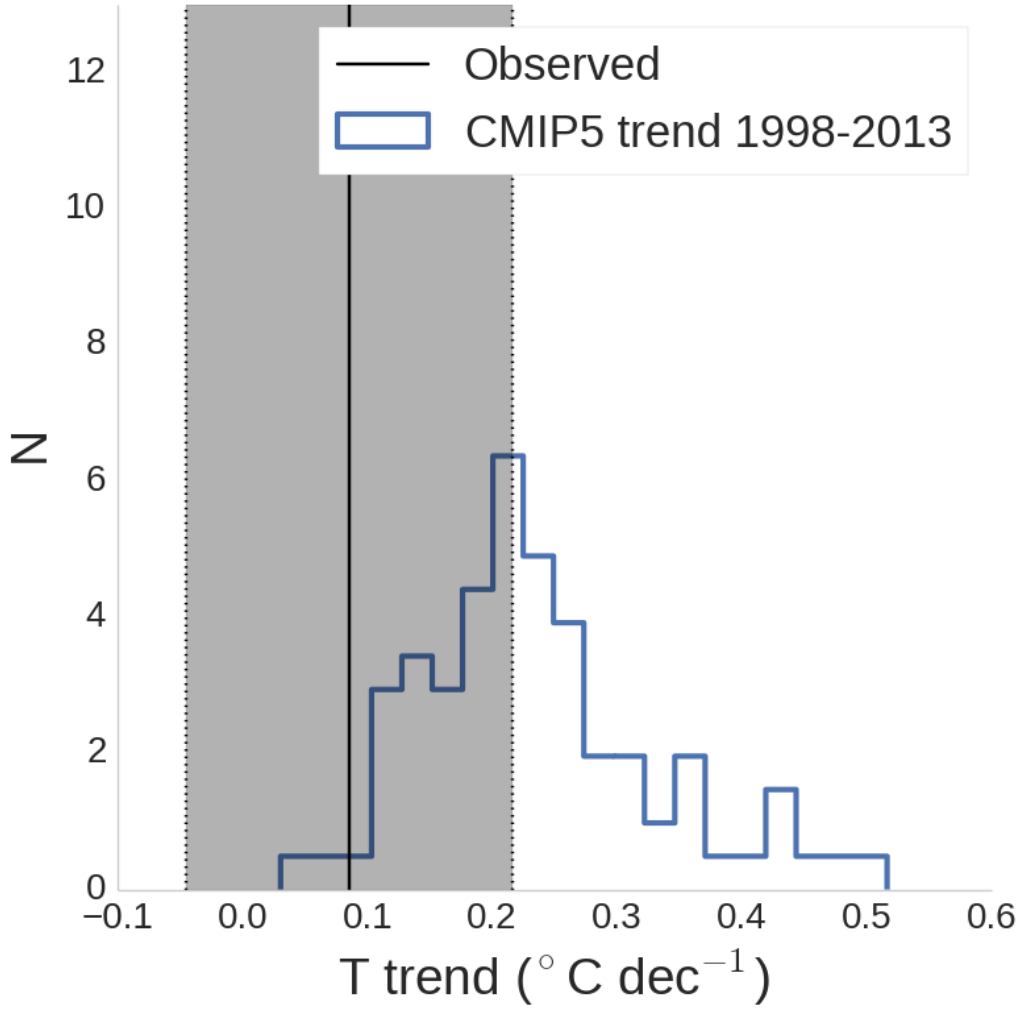
36 % of simulations show 1998—2013 trends outside observed ±2σ



There’s no statistical evidence of a change in observed trend

…but 38 % of simulated trends are outside NOAA trend range.

Little factors

Why is there a disagreement between some models and obs trends 1998—2013?

1. We picked a period *because* of low trend, this screws with stats

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2. Models were driven with greater post—2005 forcing than actually happened (stratospheric vapour, solar activity, mid-level volcanism).

Stratospheric water vapour: Solomon et al. (2010) *Science*, doi: 10.1126/science.1182488
Solar activity, aerosol, mid-level volcanism: Kaufman et al. (2011) *PNAS*, doi: 10.1073/pnas.1102467108

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Little factors

Why is there a disagreement between some models and obs trends 1998—2013?

1. We picked a period *because* of low trend, this screws with stats
2. Models were driven with greater post—2005 forcing than actually happened (stratospheric vapour, solar activity, mid-level volcanism).
3. Model and observed temperature comparisons are not consistent

Consistency of comparisons:
Cowtan et al. (2015) *GRL* doi: 10.1002/2015GL064888
Richardson et al. (2016) *Nature Climate Change* doi: 10.1038/nclimate3066

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BIG FACTOR… The Oceans

WeatherNationTV.com (used with permission)

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BIG FACTOR… The Oceans

Image source: LA Times

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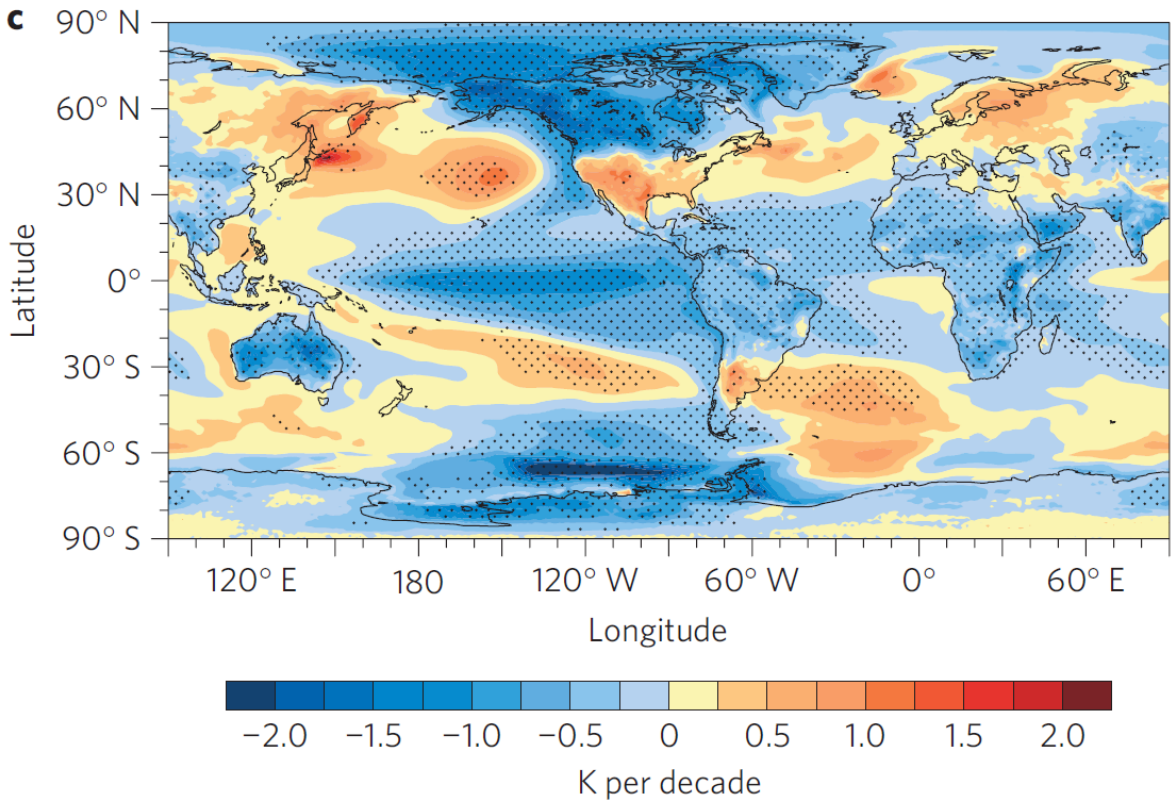
Decades in which climate models have a lower trend show specific temperature patterns

Climate model trend pattern for low-warming decades



Held et al. (2011) *Nature Climate Change* doi: 10.1038/NCLIMATE1229

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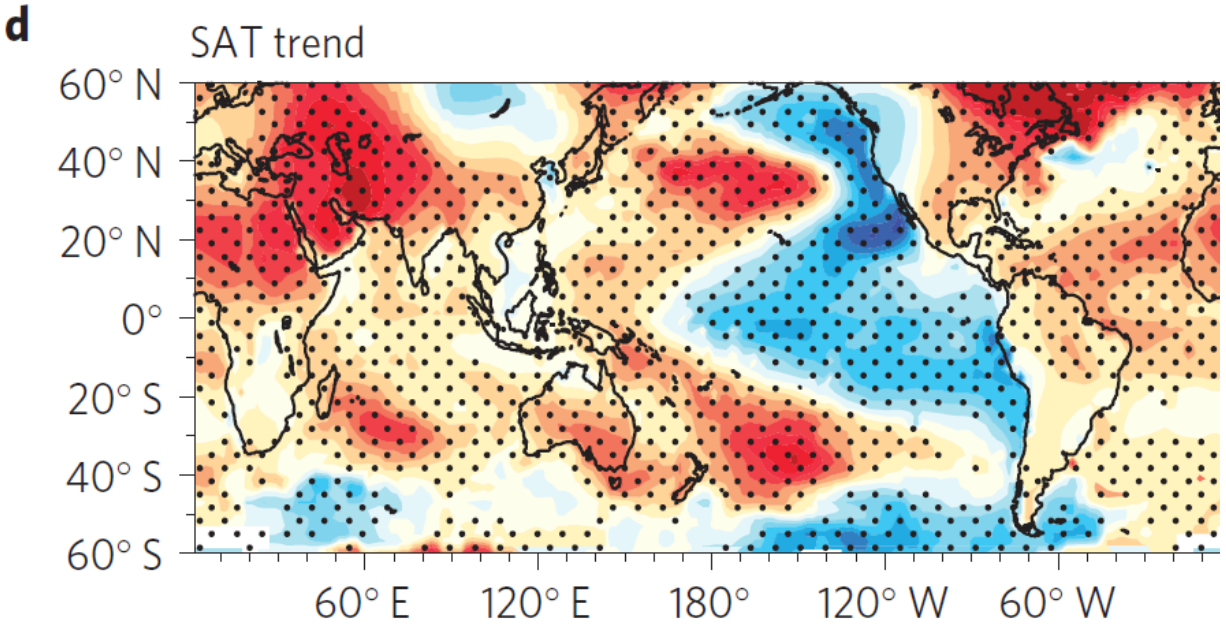
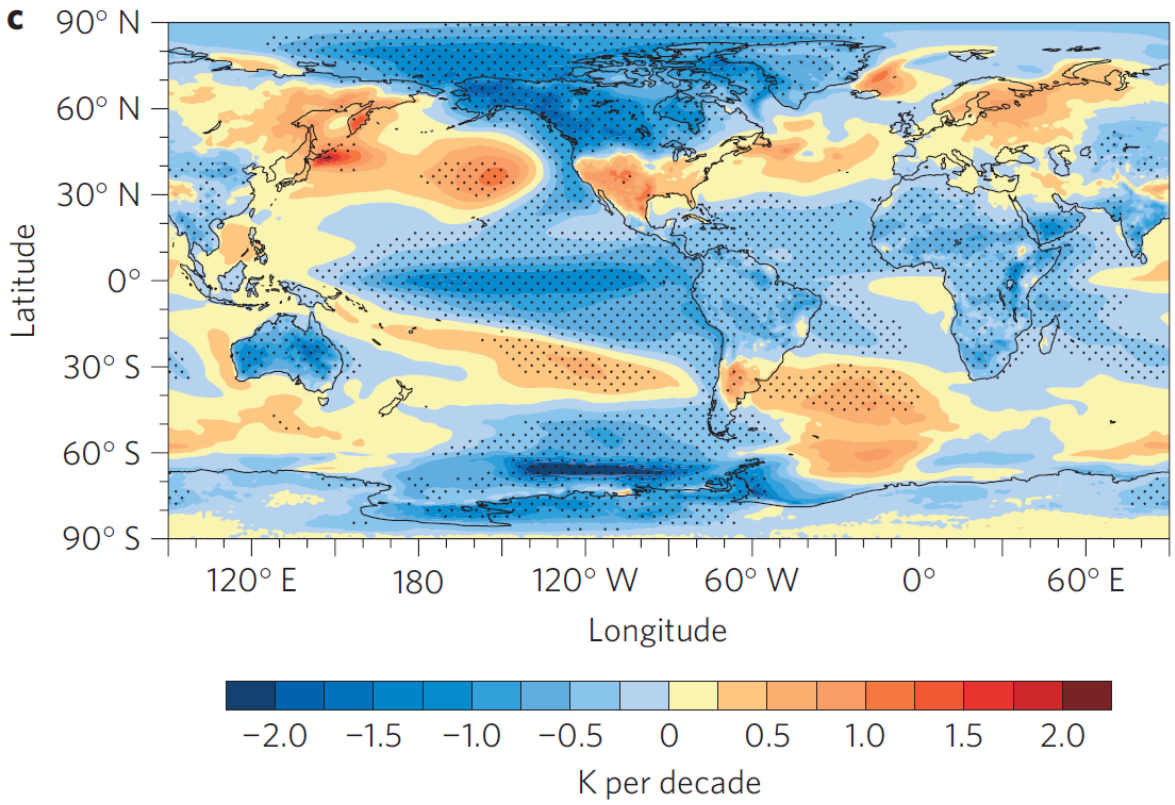
Looks a lot like 1998—2011 in Pacific



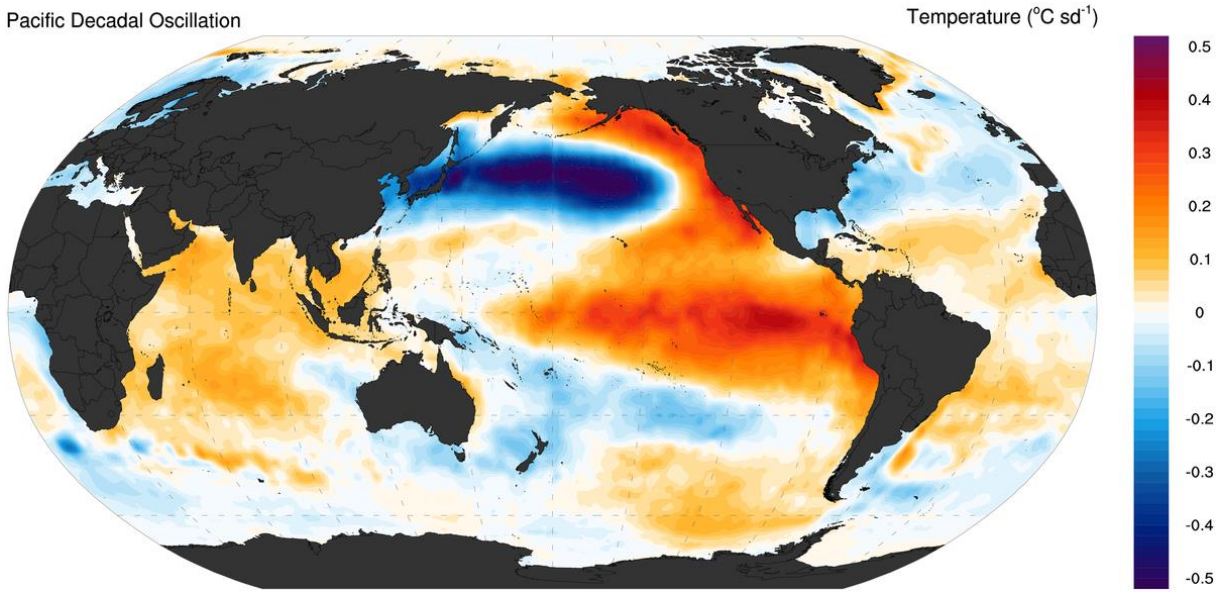
England et al. (2014) *Nature Climate Change* doi: 10.1038/nclimate2106

Climate model trend pattern for low-warming decades



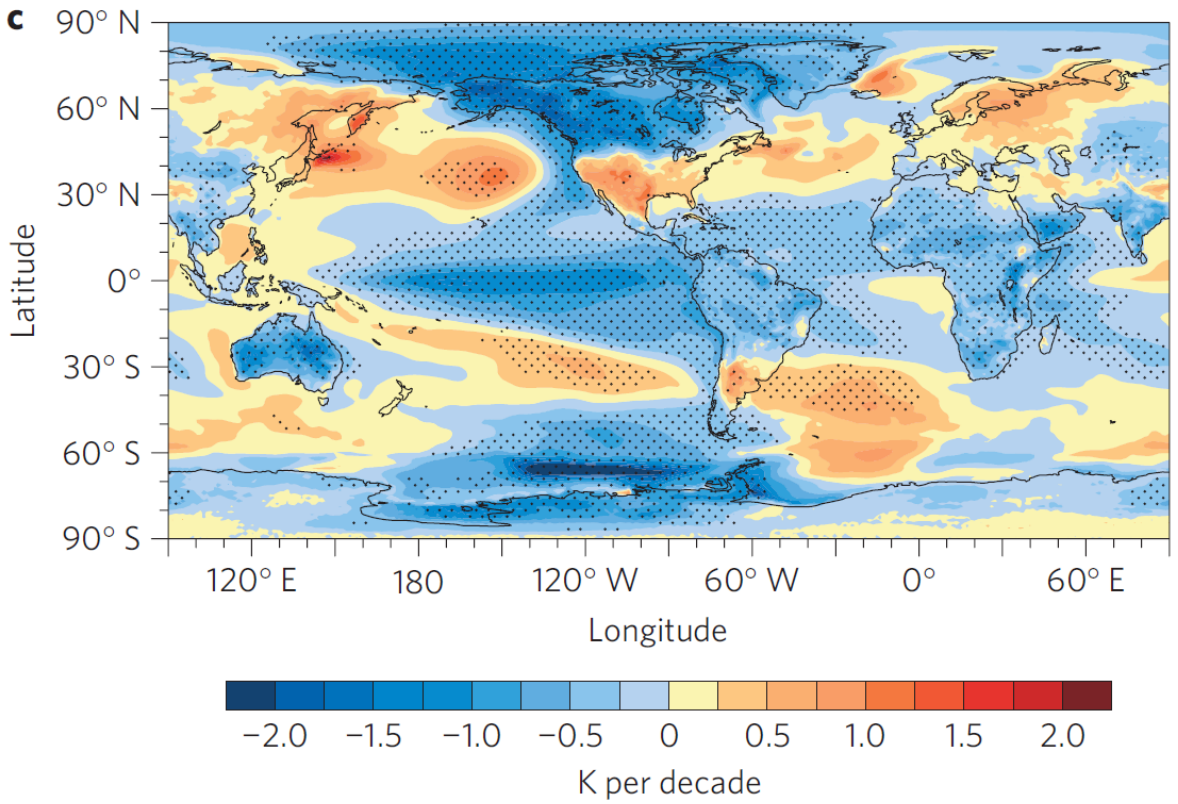
Held et al. (2011) *Nature Climate Change* doi: 10.1038/NCLIMATE1229

Looks a bit like inverted PDO

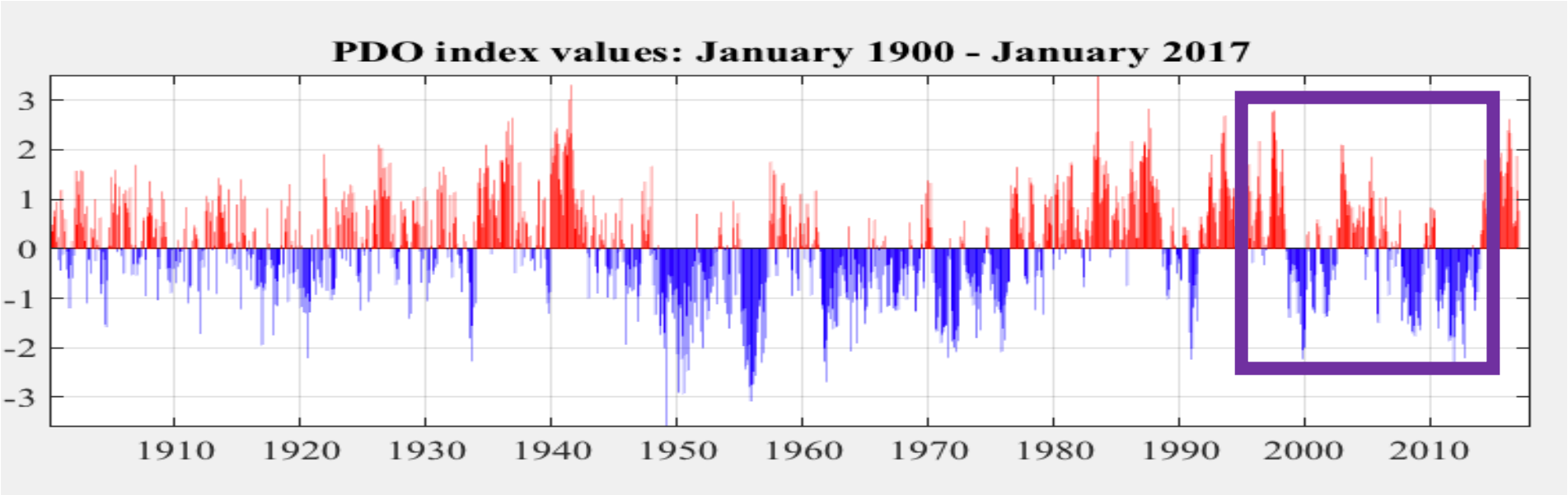


Source: Wikipedia

Climate model trend pattern for low-warming decades



Held et al. (2011) *Nature Climate Change* doi: 10.1038/NCLIMATE1229


PDO index values: January 1900 - January 2017
3
2
1
0
-1
-2
-3
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

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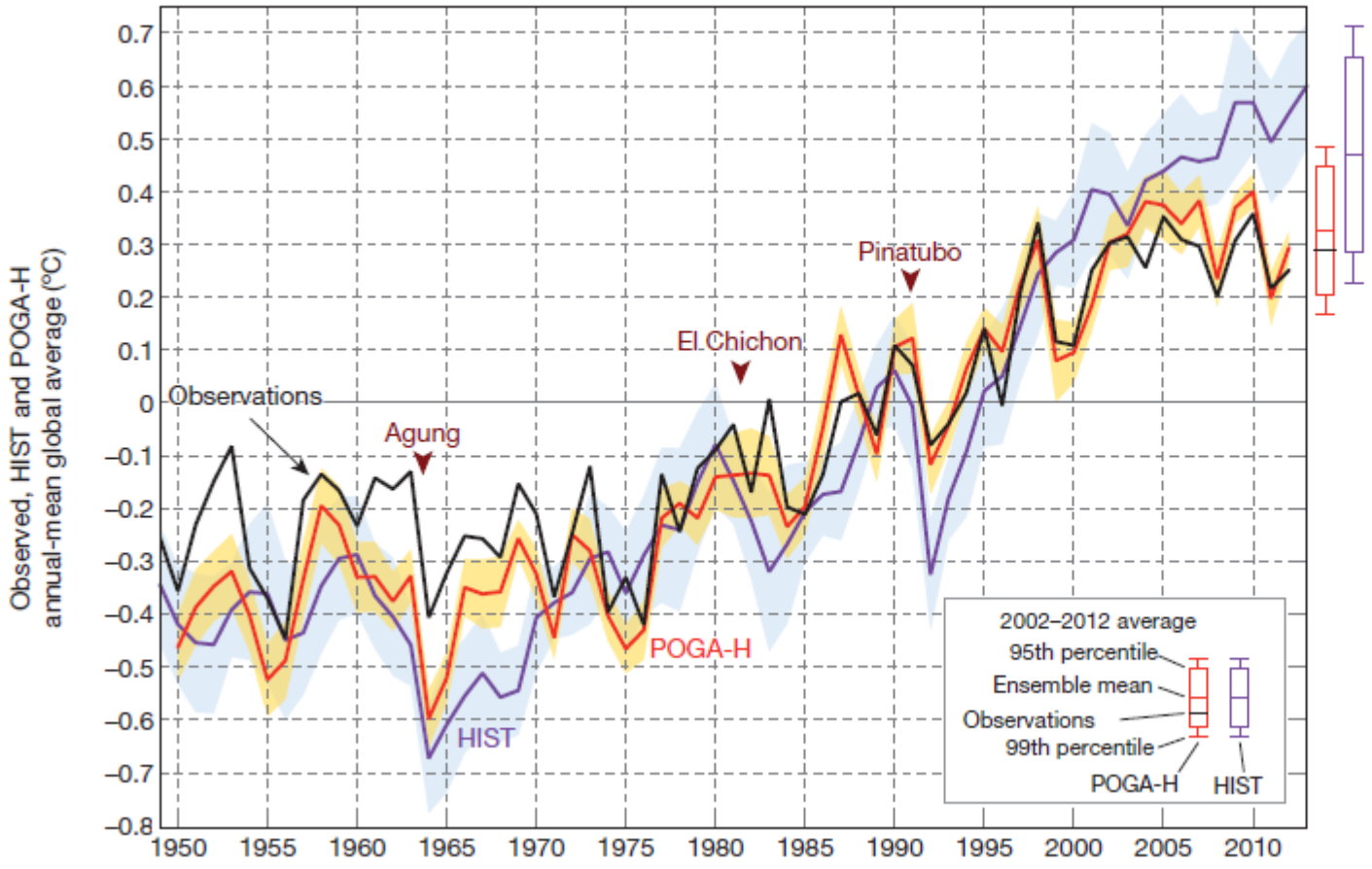
Providing surface temperatures in Eastern Pacific region to climate model, and global temperatures match better



global temperature trends. Annual-mean time series based on observations, HIST and POGA-H (**a**) and on POGA-C (**b**). Anomalies are deviations from the 1980–1999 averages, except for HIST, for which the reference is the 1980–1999 average of POGA-H. SAT anomalies over the restoring region are plotted in **b**, with the axis on the right. Major volcanic eruptions are indicated in **a**. **c**, Trends of seasonal global temperature for 2002–2012 in observations and POGA-H. Shading represents 95% confidence interval of ensemble means. Bars on the right of **a** show the ranges of ensemble spreads of the 2002–2012 averages.

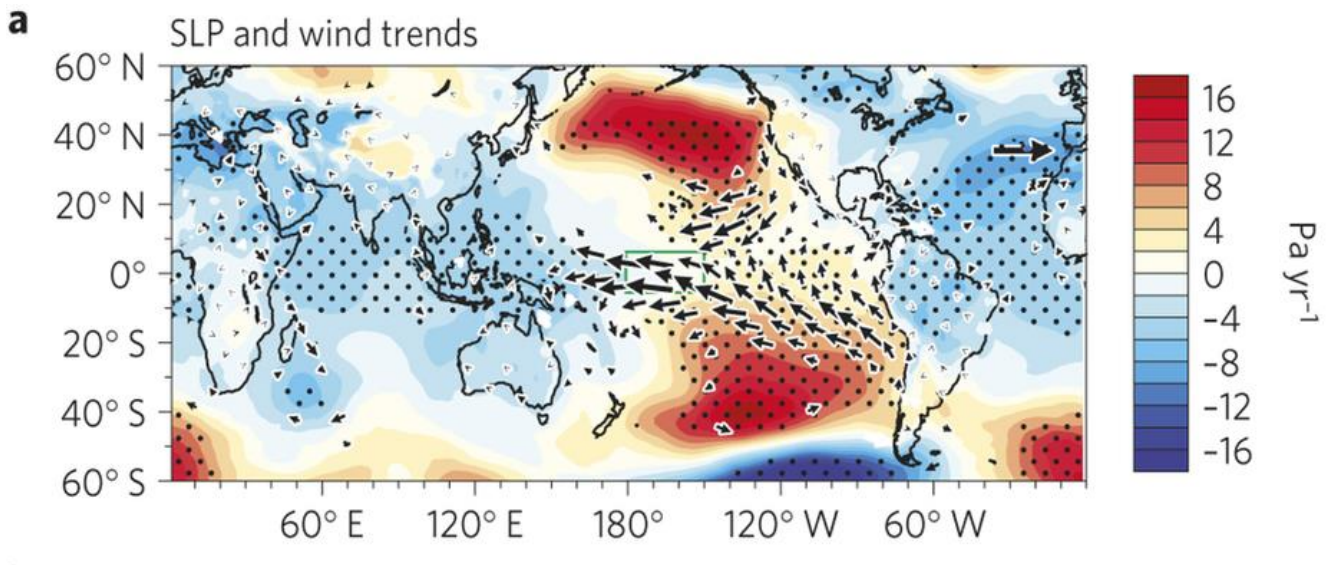
Kosaka & Xie (2013) *Nature* doi:10.1038/nature12534

Some other findings

- Climate models that have similar Pacific variability show similar patterns and trends to reality (Risbey et al)

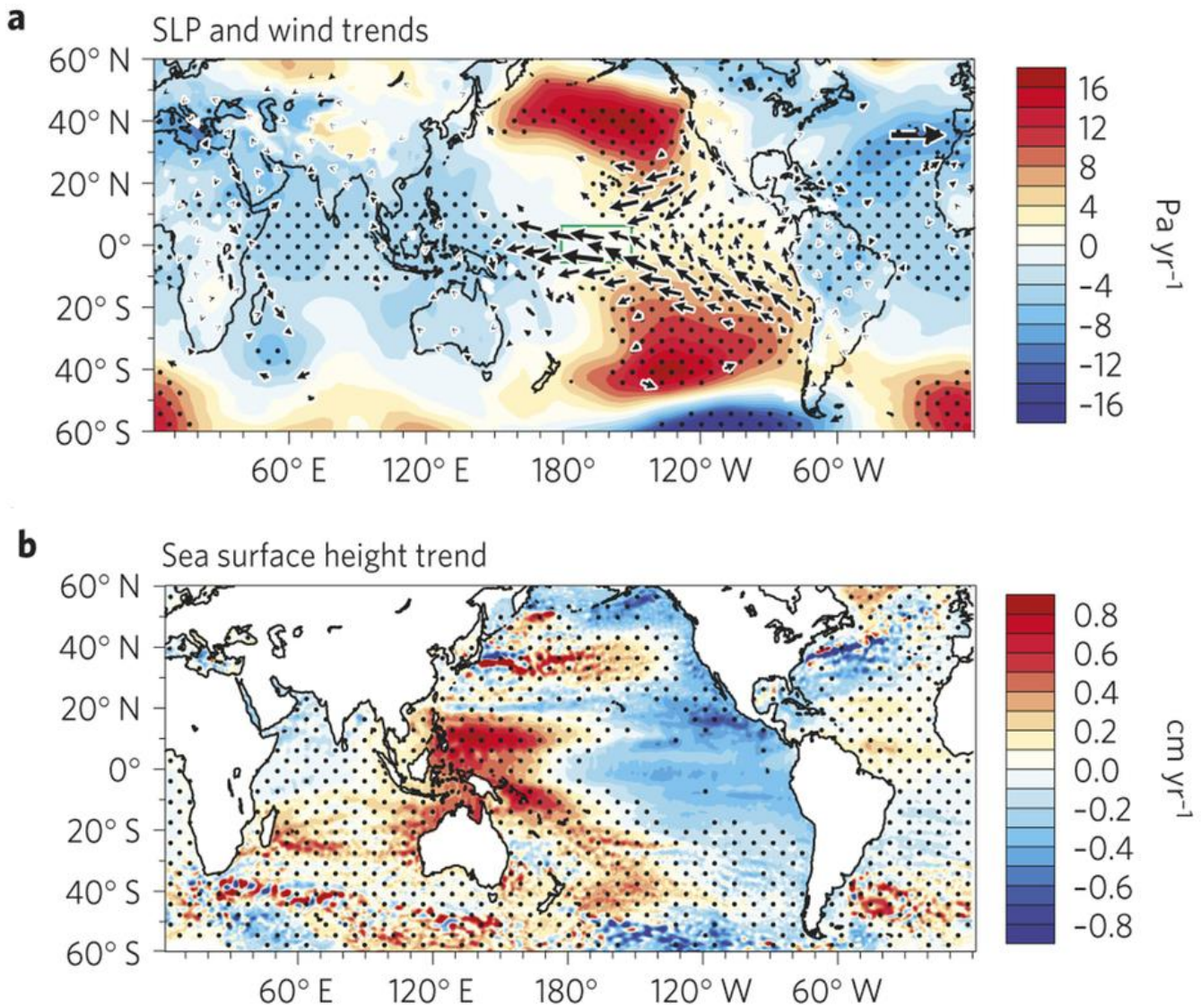
- Pacific Trades reached strongest since at least 1900 (according to 20CR), put them into model and you closely match recent patterns (England et al., 2014)

- Changes in ocean heat uptake too…



Winds pushing up from E Pacific to W Pacific

England et al. (2014) *Nature Climate Change*
doi: 10.1038/nclimate2106



England et al. (2014) *Nature Climate Change*
doi: 10.1038/nclimate2106

Ocean heating

- Studies of ocean heat content have shown it moving around too, and being sucked from ocean surface layer

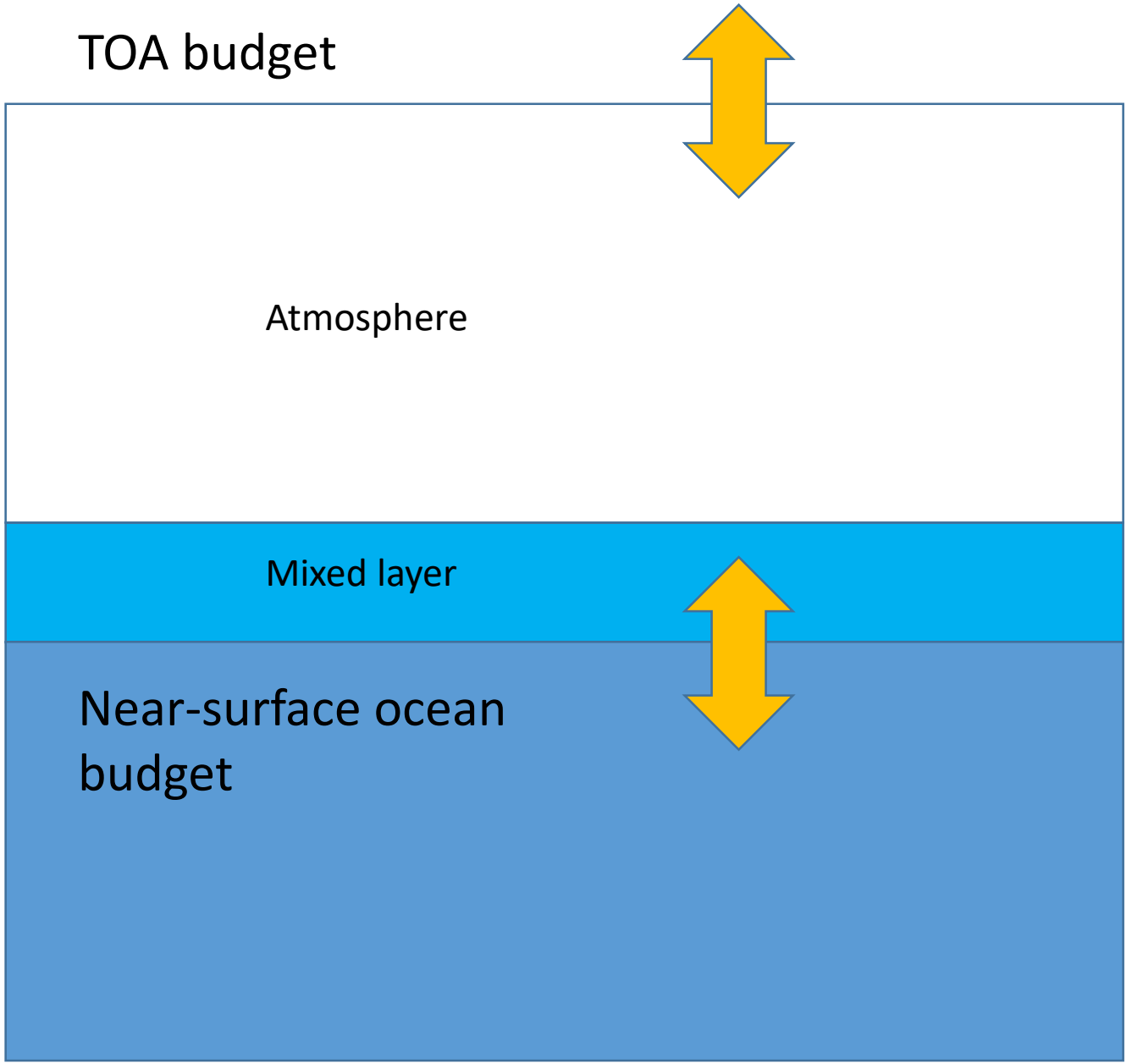
- Heating in 100—300 m layer of Pacific and Indian oceans (Nieves et al., 2015 *Science* doi: 10.1126/science.aaa4521)

From Hedemann et al. (2017)

Nature Climate Change

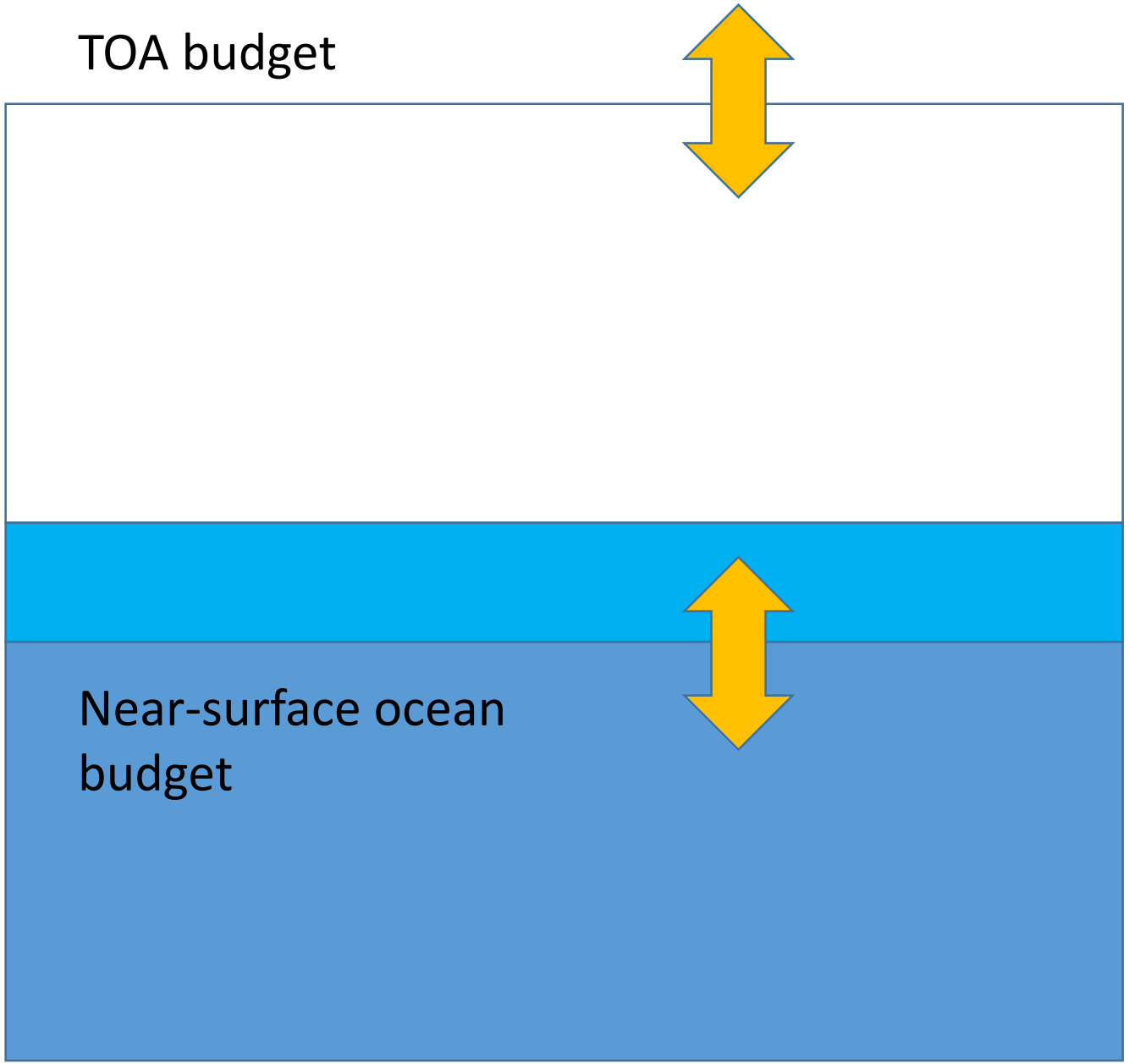
doi: 10.1038/nclimate327

TOA and ocean can compensate each other somewhat



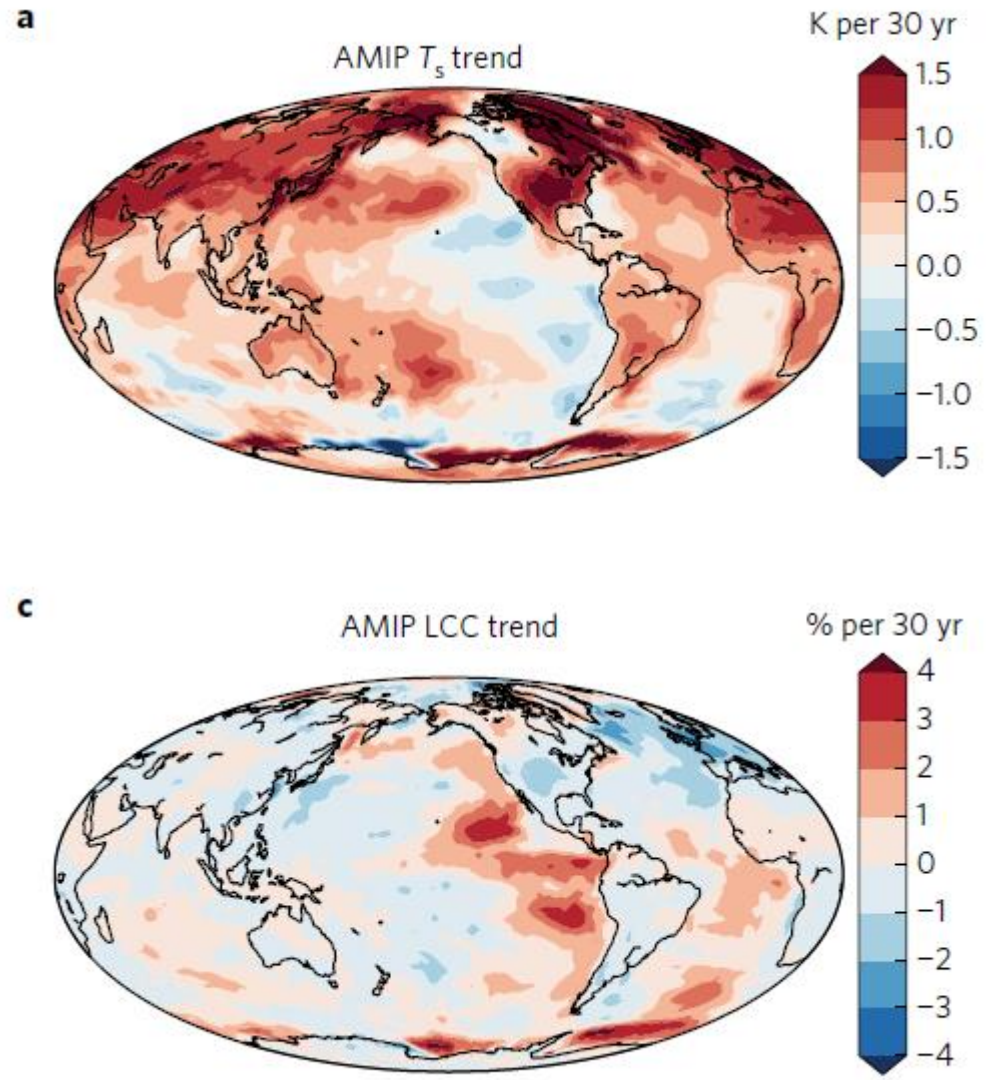
Studies looking at ocean have found sinking of heat away from 0—100 m layer (e.g. Nieves), but recent work has found something big in the TOA.

Total ocean heat uptake is 0.4—1.0 W m^{-2} and is reasonably consistent since



Clouds!

Increased Western Pacific/Indonesian warm pool convection and cooling in upwelling regions → increase in stability in upwelling regions → increase in shiny, reflective low clouds



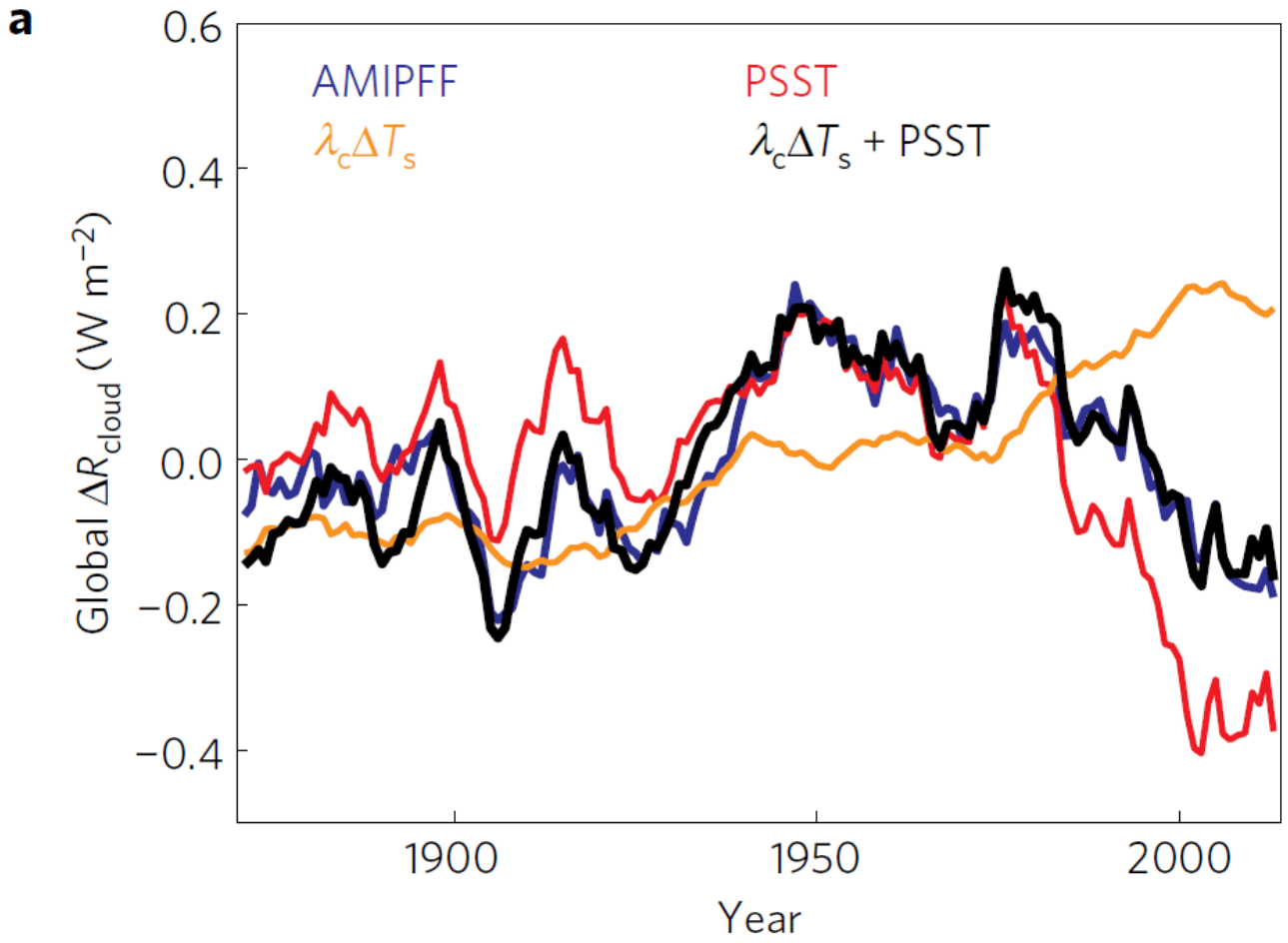
Zhou, Zelinka & Klein (2016) *Nature Geoscience* doi: 10.1038/NGEO2828

Clouds!

Model: 0.4—0.6 W m^{-2} cooling from clouds

Model matches low-cloud properties from ISCCP/MODIS pretty well

This is lots of cooling – and it's an increase that's larger than most of the ocean heat uptake changes



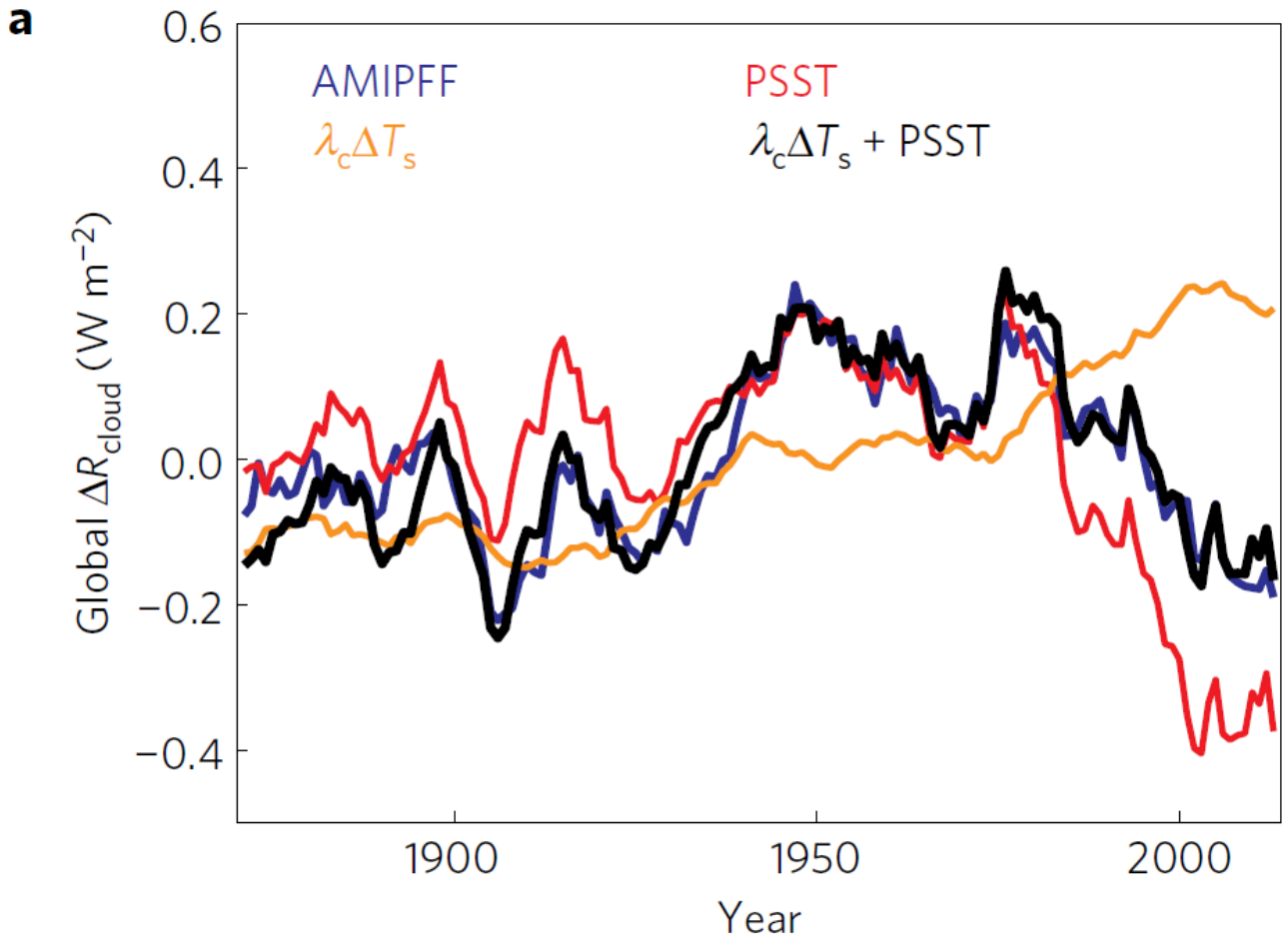
Zhou, Zelinka & Klein (2016) *Nature Geoscience* doi: 10.1038/NGEO2828

Clouds!

Model: 0.4—0.6 W m^{-2} cooling from clouds

Rough calculation gives 0.5—1.0×10^{23} J from cloud cooling over 1998—2013

This is ≥ ocean heat uptake changes that e.g. Chen & Tung (2015) IDd



Zhou, Zelinka & Klein (2016) *Nature Geoscience* doi: 10.1038/NGEO2828

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Conclusions

1. No statistical evidence of slowdown or change in T **trend** since 1970s but (**trend** + **noise**) fit 1998—2013 low vs. models
2. Strong evidence that **noise** contributed to cooling – captured through PDO index, strengthening trades, ocean heat and *changes in clouds*
3. If PDO had gone up instead, that would have supported a trend change
4. Exciting for the future! Our best understanding is that this is internal*, but it somehow forced then future warming should be less, but…
5. Don’t bet on continued strengthening of these cooling factors, and hold off on saying “acceleration” in global warming until it’s robust

*some evidence of contribution of Chinese aerosols to strengthened trades

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Simple take aways

1. New NOAA ERSSTv4 good
2. Constant global warming since ~1970
3. Internal variability tried to cool us 1998—2013

BLANK

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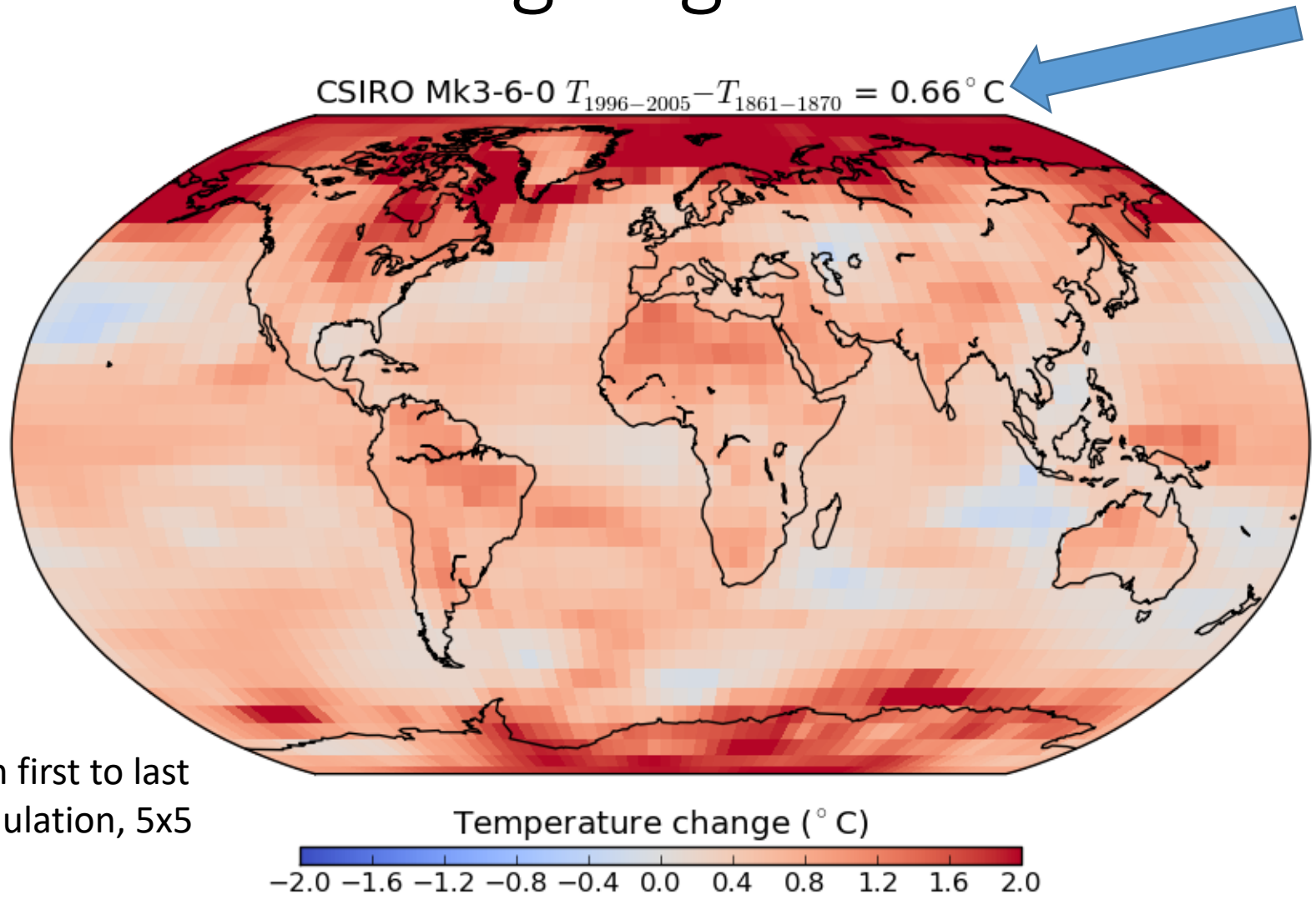
Observational coverage - global



Temperature change from first to last decade of “historical” simulation, 5x5 degree grid

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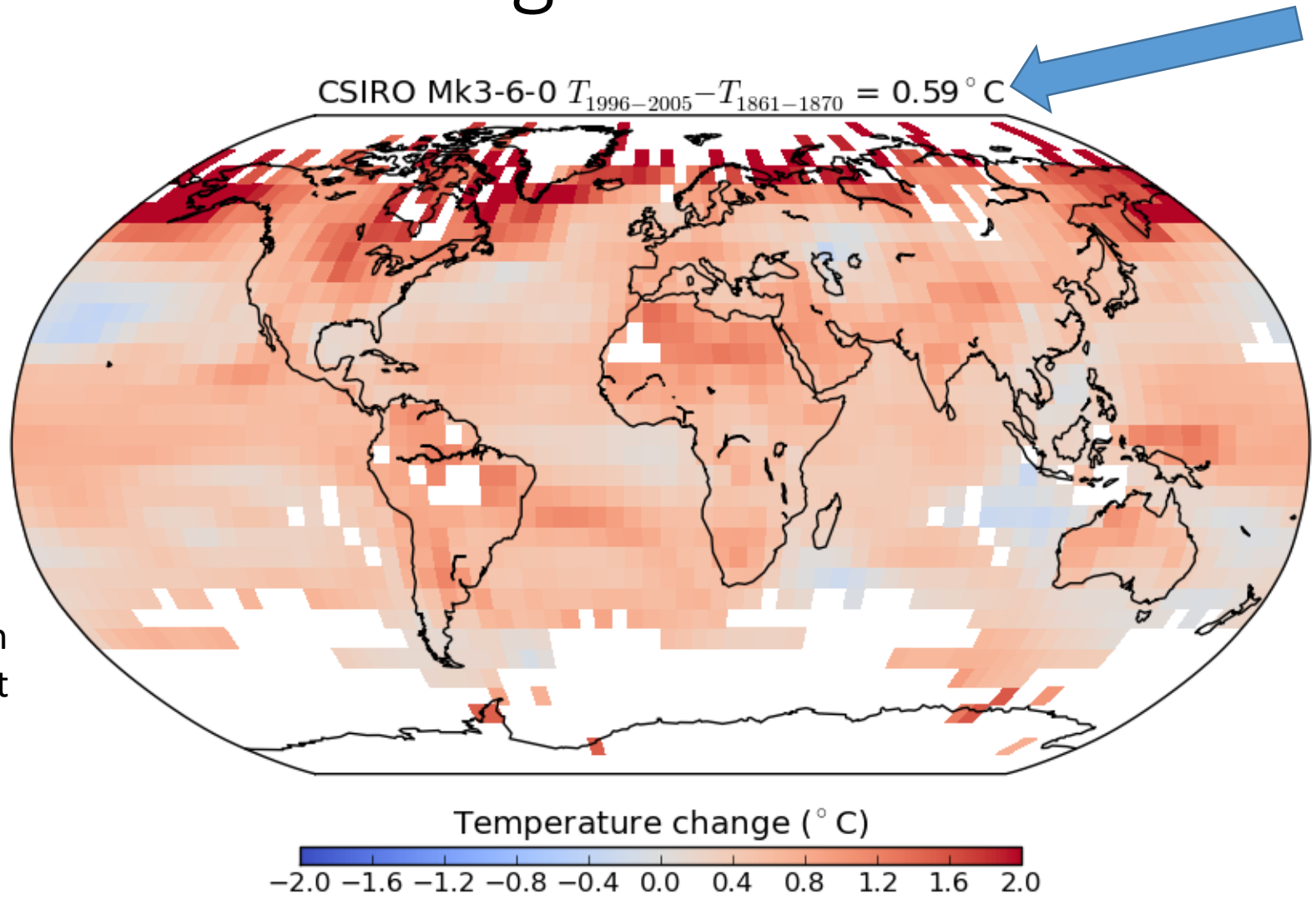
Observational coverage – 1996—2005

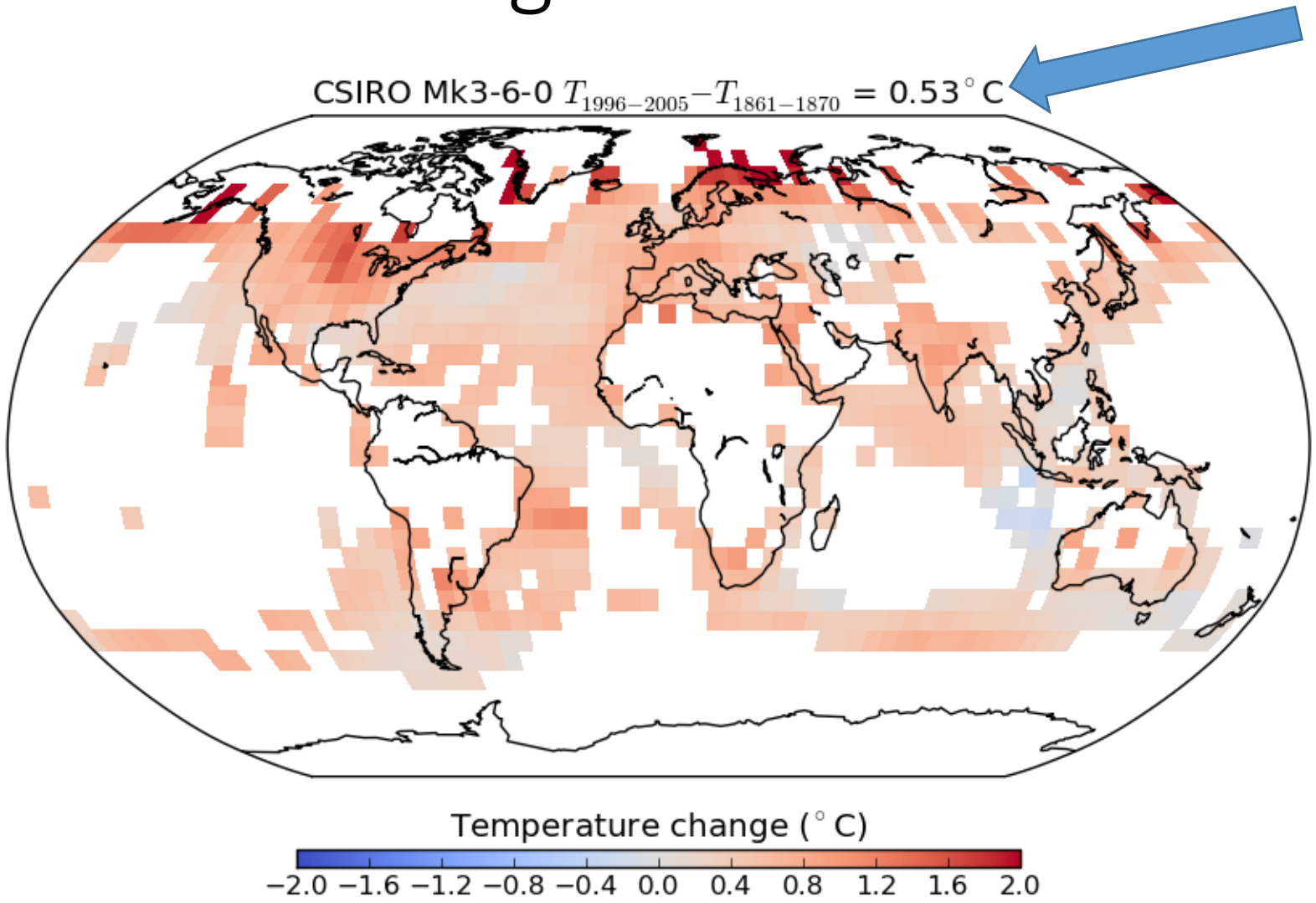
"Masking" model output to match observed geographical coverage

Shown where *any* month reported a measurement in this decade – true coverage is worse



Observational coverage 1900—1909

"Masking" model output to match observed geographical coverage



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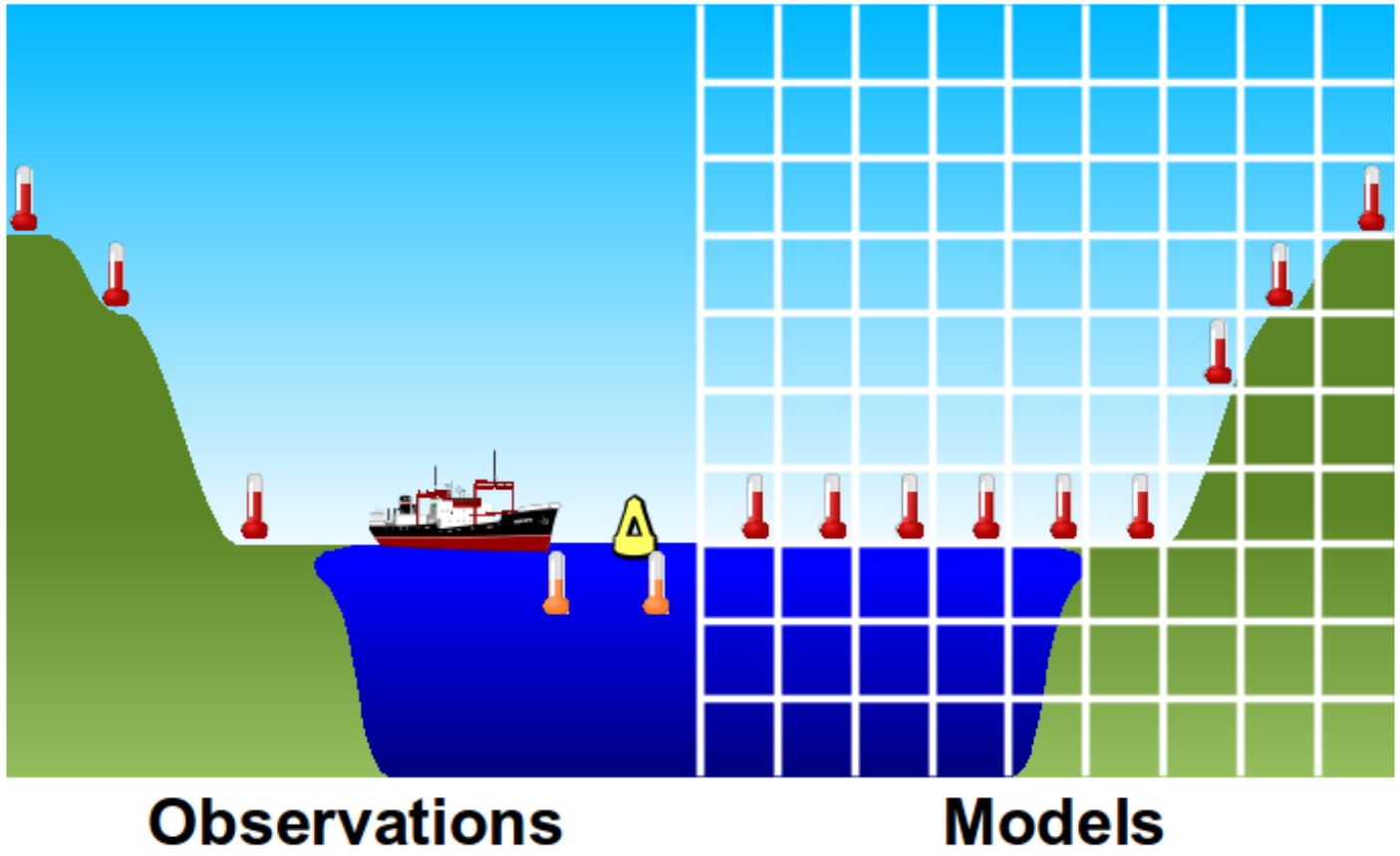
Global temperature estimates – land and ocean



Credit: Kevin Cowtan

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“Hiatus” talk

Chang and Tung say:

“Therefore, the enhanced ocean heat sink is the main cause for the current slowing in surface warming”

But Zhou, Zelinka and Klein calculate change of ~0.4 W m-2 in cloud forcing from pre-1998 decade to today. That’s about 200 TW, or 6.4E21 J/yr.

Kosaka & Xie 2013